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THE SYNCHRONOGRAPH.

BY ALBERT CUSHING CREHORE AND GEORGE OWEN SQUIER.

Discussion in Chicago April 21st 1897.

(Mr. A. V. Abbott, Presiding.)

Dr. Frederick Bedell:—It gives me great pleasure this evening to read a paper prepared by Dr. Crehore, with whom I have been so closely associated in scientific work, and Lieut. Squier. The paper deals with a system of high-speed telegraphy, the speed attained being far beyond the speed reached by the methods now in vogue. The paper is a long one, and as each of you have a copy of it in hand, I will pass rapidly over the minor details, and devote more time to the salient points of the paper.

Dr. Bedell then read the paper. (See p. 91.)

Prof. W. M. Stine:—I would like to have you explain how the plate is held, and the mechanism of the revolving disk, also how the exposure of the plate is effected. Is the apparatus used in the light?

Dr. Bedell:—The plate is held in a light-proof plate holder. The whole apparatus is used in the light. When used as a chronograph for determining the velocity of projectiles, the operator presses a key, and a circuit is closed which starts the projectile; the shutter is opened automatically by means of an electro-magnetic device, so that the shutter is only open during the time of one revolution of the plate. This instrument (the Polarizing Photo-Chronograph measuring instrument) can be read to one one-thousandth of a degree, and estimated to one ten-thousandth of a degree.

Mr. A. V. Abbott (the Chairman):—Gentlemen, I for one feel we have listened this evening to a paper which will take us some time to digest, and assimilate, for the bearing of the subject upon that portion of electrical science with which it deals is of great importance. The only criticism which I could make upon the paper is, that the authors have failed to show a plan for doing away with the telegraphic system entirely, and do not indicate

to us how to transmit intelligence by intuition from person to person, in all parts of the world at the same time. The salient point which has occurred to me this evening is the simplicity and at the same time the ingenuity, which the authors have displayed in their apparatus. The idea of transmitting signals by suppressing half of each wave at precisely the right time, so that the inductance of the line would have but little effect, seems such a simple and yet effective thing that we all wonder why we had not thought of it ourselves. But how to get an inertialess receiver, which was the question that occurred to me, to get something that would record those signals and place them on record, and in such shape that it could be translated and read,—it is a wonderful thing. To institute a set of signals is one thing; to receive and place them on record is a very different problem, and I think even Faraday would have been greatly surprised if anyone had predicted to him that the discovery of the effect of a magnet on a ray of polarized light could be made the basis of such an invention.

MR. W. W. RYDER:—In railroad work there would hardly be a possibility, or I should say a probability, of an extended use of this system, as there is never a large accumulation of messages between any two points that would require such speed of transmission.

I realize, however, that it would mean a great deal to the commercial telegraph companies if this scheme could be put into practical operation upon the present telegraph circuits. There is always a great amount of business constantly passing between the larger cities, and such a system would be of great benefit in quickly handling it. This would be especially true when the wires are prostrated by storms. The messages could be prepared for transmission and as soon as the first wire was repaired, the business could be started at a rate that would quickly relieve the congestion.

MR. ABBOTT:—Humanity is never satisfied and always wants something a little better, or a little quicker; though I have heard it said that when railway postal facilities were first talked of, they were objected to by the more conservative as being entirely unnecessary, for had they not had a postman on horseback, who could travel five miles an hour, almost as fast as the railroad train of those days, and what did they want better than this? Besides, if there were better facilities, too much time might be spent in writing letters. When the telegraph came fifty years ago, the same objection was made; there were good postal facilities, and when the telephone came, there was the telegraph and the district messenger service. Individually I should feel that no invention could be too quick for us in this country. The faster we can work telegraph lines, the more economically the messages can be sent, and the more people will use the telegraph, if transmission can be cheapened.

PROF. C. V. KERR:—The idea that is embodied in this system is certainly a very beautiful one, and seems extremely simple. Now, looking at it from a commercial standpoint, it seems to me that at the first stage this apparatus must be limited in its use to lines where there is a great congestion of telegraphic matter. The apparatus is necessarily expensive. There must be, in the first place, the apparatus for light, and then the polarizing apparatus, and then the apparatus for getting the record after the message is prepared on the strip of paper. If the apparatus for quickening the recording of the message itself can be made as beautiful and quick and simple as are the main ideas of the apparatus, it certainly will be a wonderful system. But we have first to prepare the message itself, then develop the photographic plate. Now, that will take time, and it will be expensive, so that, looking at the system from this point of view, my first impression would be that it is going to be limited in its applications unless these points can be cheapened in some way. But it is not safe ever to say too much as to what can be done with a new invention, for again and again our ideas have been set aside by later developments.

MR. ABBOTT:—The complexity of the apparatus is certainly at present formidable, but, as Prof. Kerr has pertinently added, a new invention is always more complicated than it is in its succeeding steps. It is not impossible that simplification may occur in a very marked degree. Furthermore, even with its present complexity, it is not impossible that the cheapness of wholesale business might render it an eminently successful system. I think if photographers ten years ago had been presented with the kinetoscope and its companions of a similar nature, and had been asked to take twenty or thirty pictures per second, as is now successfully done, they would have said it was impossible, or if possible, would have been too expensive, while it is an actual fact that the cost is entirely within commercial bounds.

MR. F. E. DRAKE:—I confess to some considerable degree of interest in this very charming paper, having had several years experience in the telegraph. I realize the step that is here expressed, in passing from perhaps forty to fifty words a minute to three thousand words a minute, and believe there are a great many points of possible development in this system. With my limited experience in the old style telegraph, I can predict that under the careful scrutiny and painstaking zeal and ingenuity of these gentlemen, they will be able to accomplish a result which will be of great benefit to the entire world. We are so accustomed now to receiving intelligence with marvelous speed from all points of the globe, that this method is only in touch with what we most desire. From a technical standpoint, I do not feel in any way competent to express an opinion. The question of photographic plates seems to me the most serious which rises in connection

with this device. Another thing which occurs to me is the fact that you have to go through almost all of the old methods in order to get your message readable, although the speed attained in transmitting is marvelous. Then again, the receiving of the messages and getting them into condition for the understanding of the press and the public at large, adds to some pressing commercial features of the present code. I believe that one of the most important advances which will be made in this direction will be the simplification of the codes to be used, and the introduction of a new scheme of phonographic telegraph, expressing synchronously words, phrases and sentences. That one point strikes me as being the greatest possibility of this new invention, and I predict we will hear from it with a great amount of interest.

DR. BEDELL:—Some of the speakers have expressed their opinion that this system is exceedingly promising, but that it possesses obstacles, which, although of minor importance, may be serious in practical ways. They have also suggested the overcoming of these obstacles as a matter of future development. Such is the case. The first endeavor is to establish the feasibility of the system, and to develop some plan which will be operative. After going thus far, and demonstrating by a series of experiments that the system is a practical one, it is proper time to determine the exact form of apparatus which will be simplest and best. For instance, the instrument shown on the screen, used as the polarizing receiver, was one constructed for chronographic purposes, with no definite consideration so far as telegraphy is concerned. However, the authors of the paper have developed two forms of receiver, one of which has been partially neglected in the discussion this evening,—the chemical receiver. The chemical receiver may be used, and it was dwelt upon at less length because it needs less explanation. The polarizing receiver was discussed more at length because more of the early experimental work was done on that receiver, and it has many features which are worthy of consideration. The chemical receiver, however, in the minds of the inventors possesses many points of superiority over the polarizing receiver. They thus secure a receiver which possesses a degree of simplicity comparable with that of the transmitter. In regard to the polarizing receiver, it may be said that a simplification has already been made. The authors of the paper suggest the use of a continuous tape instead of a disk, this tape passing through a developer, and coming out already fixed. It seems that this apparatus could be arranged so as to be, in a way, comparable with the chemical receiver. There is no doubt that if the system receives careful attention, as it is sure to do, sundry details will be perfected, and simple instruments devised. This development, however, would simply be in the way of modification of the general idea, that is, of transmit-

ting signals by suppressing distinct predetermined half-waves of an alternating current, and to receive them by some kind of massless receiver.

MR. ABBOTT:—I think that Prof. Stine has voiced the thoughts of most of us, particularly, if we take into consideration the capacity of the apparatus proposed. This device, undoubtedly, would be very expensive if it were to be applied only to the transmission of a few words a day, or messages of a few words each. But even a fraction of its capacity would indicate that it undoubtedly would be very much cheaper than any system we now have. It is, undoubtedly, somewhat complex, and may require considerable apparatus and skill for its installation and operation, but it will enable transmission to be sent with marked economy over anything now in sight. I think we should have but little doubt but that the volume of business would come just as soon as a commercial showing indicates the possibility of cheaper transmission than we now have.

MR. W. D. BALL:—First of all, I want to add my little mite to the words of praise which have been given to the paper read to-night. I am like a good many others who are here,—I have not been able to digest it, but I am something like the small boy who can ask questions, if he can't do anything else. There are a few points which I would like Dr. Bedell to take up more at length, if possible, with regard to the practical application of the working of the apparatus. In the first place, I might say I would not be willing to admit at present its greater economy in the matter of transmission of messages until we have some practical data regarding the amount of time taken for preparing the ribbons and photographic plates, etc., and for the expense of the force necessary to take care of the transmission, repetition and recording of messages. The figures shown on the screen have aptly illustrated the paper, but I believe nothing was said with regard to the amount of energy necessary to transmit messages. I take it, of course, that the difference of potential impressed upon the circuit would depend almost entirely upon the length of circuit, the resistance to be overcome, etc. If Dr. Bedell can, I should be very glad to hear him tell us of the voltages used, and give us what other practical data he may have regarding it. It is unfortunate that we did not get copies of this interesting paper in time to have read them over. Possibly these points are touched upon in the paper. At the same time, I should like Dr. Bedell to dwell a little more at length on the effect of induction in the lines and the possibility of long distance lines, both as affected by the inductance of the lines and by the frequency of the alternations.

DR. BEDELL:—I regret that the inventors are not here to answer some of these inquiries, for they are all questions of detail with which I am not sufficiently informed to give adequate answers. I do not know the exact electromotive force employed in their experiments; nor do I have practical data concerning

the line, its length, capacity, and resistance. The line was a short, experimental line, which had its actual length increased, however, by resistances inserted in the laboratory, and the authors have made computations as to the feasibility of long-distance telegraphy, which has resulted favorably. If it does come, however, to a question of increased cost of line construction, as it undoubtedly would where there are long distances, as across the continent, we could well afford to put a good deal of money into a line where we had but one to maintain, instead of many. One point concerning the labor of preparing the perforated tape: the labor, unless some special device is introduced, would be the same, no more and no less, than there is now in the methods of machine telegraphy. It has been suggested by the authors that the work of translation, so to speak, be thrown upon the individual. That is, we dictate a letter to our stenographer, who transcribes it upon the typewriter by performing two operations at once, one, preparing a copy of the letter in readable form for preservation, and the other preparing the perforated tape. This perforated tape is then put in an envelope and dispatched to the sending station. The sending station would not then need a large force in transcribing messages, but simply enough men to operate the machine proper, the other work being transferred to the private office. However, too much cannot be done at once. The step which has been taken is to eliminate the time element in the necessary part of the transmission.

MR. LOUIS PRIVAT:—I should like to ask Prof. Bedell one question before we close our discussion. Could this system be applied to Trans-Atlantic cables? It seems to me that this is a place for great economy, if it could be used in that manner. It seems to me that an invention of this kind, which would distribute so much intelligence in such a short time, would be particularly desirable there, where, under the present method, transmission is so expensive. This system would undoubtedly be much cheaper.

DR. BEDELL:—Cable transmission by this system has not yet, I believe, been subjected to experiment. It has been contemplated by the authors, and a cable has been placed at their disposal to be used at such time as they are ready to undertake that experimental work; but the time at their disposal has not yet allowed them to avail themselves of this opportunity, for they have found so many other points of detail to occupy their attention that they have had to forego this experiment. I do not doubt, however, but that it will be taken up in the near future.

PROF. STINE:—We have all been delighted with the paper which has been presented to us this evening, and the very clear, full explanation which has accompanied its presentation. I think all present will cordially join me in a vote of thanks to Dr. Bedell for his kindness in coming to us to read the paper, and taking such an interest in explaining it.

(The vote of thanks was unanimously carried.)

Discussion in New York May 18th, 1897.

(President Duncan in the Chair.)

Mr. Francis W. Jones:—The proposition to increase the efficiency of the electric telegraph by the employment of some automatic system that will admit of the transmission of several hundred and even thousands of words continuously per minute has been a favorite one, not only with visionary and impractical minds unfamiliar with the every day demands of the telegraphing public, but the idea has been cherished by practical telegraph engineers of the most distinguished ability ever since the conception of the electric telegraph both here and in England, the two countries that have led all others in bringing to their present state of perfection the wonderful systems that are being employed upon the land and submarine wires of the world.

It is not complimentary to the managers of the great telegraph systems of the world, particularly those of Great Britain and America, to suppose that they would go on year after year putting up hundreds of thousands of miles of new wires, the majority of which are pure copper, to meet the increasing demands of the public, or to allow the post office to carry an enormous volume of mail matter by railroad, when by the employment of a system similar to the one proposed, as much business could be transmitted from New York to Chicago in 10 hours by one wire, as is now done by 100 wires worked quadruplex.

That there have been very high speed automatic systems put in operation at a great expense is a matter of record, and I believe that the failure of such systems to bring about a cheaper and more rapid handling of telegrams was in no way due to inability to transmit and record the signals fast enough over the wire, but was due to other and very different things, so I do not deem it necessary at this time to enter into any discussion of the particular method of transmission proposed under the name of the "Synchronograph," but will endeavor to present a few stubborn facts which so far have stood in the way of the realization of the joint inventors' vision of the practical application of sending 3,000 words per minute between New York and Chicago, and performing the entire postal service represented by 40,000 letters daily upon two telegraph wires.

Latimer Clark, President of the Society of Telegraph Engineers (now the Institution of Electrical Engineers) in his inaugural address in January, 1875 in giving a history of the development of the British telegraph system under the various companies prior to its consolidation with the post office by the British Government, said:

"The chemical printing telegraph of Mr. Alexander Bain deserves a special notice. Chemical telegraphs were suggested at an early date, and in 1838 Mr. Edward Davy patented a chemical marking telegraph of considerable merit employing calico tapes moistened with iodide of potassium. In 1846 Mr.

Bain patented his system, and in addition to the use of an iron style resting on paper moistened with a solution of ferro cyanide of potassium described the important principle of setting up the messages on perforated paper, a system which has done more to increase the capabilities of the telegraph than any other invention.

"That invention was exhibited to the Electric Telegraph Company, and while being examined, one of the regulating springs broke and allowed the instrument to travel around with uncontrolled speed. To their surprise they found that the whole message was visible and had been transmitted correctly at the rate of several hundred words per minute upon which they resolved to purchase the invention without delay. I believe Mr. Bain received £7,000 for his patent."

"They employed the system of printing on chemical paper for some years until it was eventually supplanted by the Morse inking system. Nothing however was done with the punched paper until Sir Charles Wheatstone introduced his very beautiful automatic printing telegraph which is the most rapid system of telegraphing at present in ordinary use.

"Real capabilities of the Bain system remain however to be yet developed. The Americans have recently reintroduced it with startling results, and have shown that on ordinary circuits 400 or 500 words per minute may be readily transmitted by its means. When the capabilities of this system become generally known to the public, it will doubtless insist on enjoying the advantages to be derived from it, either in the form of lengthened messages or a lowered tariff.

"Without some such system much of the celerity to which we are now accustomed will be lost amidst the enormous accumulation of work which must sooner or later fall upon the telegraphic system of this country. The electric telegraph is quite capable of transmitting a large portion of the business of the country which is now transacted by letter, and is being so employed more and more every day. If this expansion of traffic be accompanied by facilities for securing rapid transmission for important messages the pecuniary gain to the post office will be very great, while the benefits afforded to the commerce of the country will be enormous."

Mr. Clark was engineer for the principal English telegraph company prior to its being absorbed in the government system in 1870, at which time a uniform rate of one shilling for twenty words with addresses had been adopted, and the public led to believe that by bringing the lines of five or six different companies under the management of the post office, and by the use of the Wheatstone automatic system, that an enormous volume of business could be so economically and readily handled that the tolls could be lowered almost to postage rates.

According to Mr. Preece's paper read before the London

Society of Arts in May, 1887, the Wheatstone automatic system had been constantly improved until it had a transmitting capacity between London and Ireland through the channel cables as follows:

Year.	Words per minute.
1870	50
1875	70
1880	150
1885	250
1887	450

The number of messages transmitted by the British system, immediately after the transfer to the government under the shilling rate, was about 12,000 messages of 30 words each per day, which upon the basis of calculation that has been usually adopted by the advocates of high speed telegraphy, could have all been done in eight hours upon 5 Wheatstone duplex circuits at the rate of 80 words per minute each way. Notwithstanding this we find that Mr. Preece in the foregoing mentioned paper states as follows:

"The rapid increase of business that resulted from the uniform shilling tariff soon led to the erection of more wires, and the multiplication of wires soon attracted attention to methods of duplexing and quadruplexing the circuits. The duplex system means a mode of sending two messages in opposite directions at the same time. This was shown to be possible by Gintl, in Vienna, in 1853, but the necessity for such a system did not arrive until 1872, and as the moment a want is felt something is sure to turn up to supply this want, so when the duplex was needed, Mr. Stearns arrived from America, with a well worked out practical system that was at once adopted, improved, and perfected. Still further congestion arising, quadruplex working, or the art of sending four messages on one wire at the same time, became desirable, and a practical quadruplex system, due to Mr. Edison, was imported in 1877 from the same inventive and practical, region, the United States. Later on in 1885, a still further development was matured in America, viz., the multiplex system of Delany, by which six messages can be simultaneously sent, which we have adopted, and the main features of which I now show you in action. The chief reason why these systems have been matured in America is that the want has been experienced there before here. Neither system was invented in America—each was invented in Europe. There are other wants that have been experienced here before there, and those who have visited the States have found that English inventions are equally appreciated and adopted there. It is in automatic telegraph that we have made the greatest advances."

The editor of the London *Telegraphic Journal*, January 1st, 1875, says, "The Postal Telegraph Department has during the year (1874) introduced the sounder as much as possible, and it may be now definitely considered as the instrument of the future;

its various advantages have at last become apparent, and in time we shall observe its use as wide and extended as may be seen in the United States."

"The duplex continues to advance, and the Stearns system is rapidly becoming extended. The advantages derived from the system of duplex working have daily become more and more apparent."

In 1885 the clamor of the press and the pressure of the various provincial Chambers of Commerce caused the British Parliament to inaugurate a telegram rate of sixpence for twelve words, counting addresses and signatures, and a press day rate of 75 words for one shilling, and between 6 P. M. and 9 A. M. a night rate of 100 words for one shilling with addresses free, and twopence for every drop copy.

To prepare for the expected increase in business $2,500,000 were expended to meet the increased traffic, of which $2,375,000 were expended for new poles, wires, and instruments. There were added to the system:

850 miles of pole line, 9,200 miles new wires thereon, 11,600 miles new wires on old poles, 40 sets Wheatstone automatic, 8 Morse quadruplex, 300 Morse duplex, 350 Morse sounder circuits, 150 needle sets.

One month prior to October 1st, 1885, when the sixpenny tariff went into effect, the London Central Station was equipped as follows:

Metropolitan Department: 50 sets duplex sounders, 75 sets relay duplex, 71 Morse single sets, 55 sounders, 133 needles, 4 dials.

In the Provincial Department: 32 Wheatstone sets duplexed, 58 Wheatstone sets single, 17 quadruplex, 18 duplexed registers, 93 duplexed sounders, 45 Morse sets, 37 sounders, 28 needles.

Making the total number of circuits 698 Morse, 161 needles, 4 dials and 122 Wheatstone.

The Wheatstone sets were located in the news division of the Provincial room, and about 70 transmitters were kept busy sending out news. The pneumatic punchers perforating three or more slips simultaneously, the same news answering the wants of newspapers in almost any part of Great Britain or Ireland, served by many diverging circuits from London, and during the year ended March 31st, 1885, 33,278,459 messages including press reckoned at the rate of 30 words per message were transmitted.

On July 25th, 1887, the Postmaster General at the English Telegraph Jubilee dinner in London after describing the development of Wheatstone's needle system said: "Then came another probably more even astounding development, the sounder instruments, by which messages are transmitted by sound without any record. I venture to believe that that achievement has outstripped the wildest dreams of imagination, and that the present

pace of the electric telegraph between London and Dublin where the Wheatstone automatic is employed, amount to 462 words a minute."

The Postmaster General also gave the number of telegrams sent through the post office of the United Kingdom in 1886 as 51½ millions including about 480 million words of press for the London and provincial newspapers, at an average rate of twopence per hundred words and the Postmaster General states that the cost to the public revenue over and above the tolls received for the press service is not less per year than one million dollars, which is practically a subsidy for the diffusion of intelligence. This sixpenny tariff had reduced the receipts per telegram from 1s 1d to 8d, netting for the year ended March 31st, 1886, a loss of $1,115,000 which added to the interest due on the capital stock of purchase (viz $54,402,855) amounts to a deficit of $1,857,770 or a grand total loss of $12,765,045 since the public tried to do its own business at rates below cost.

Notwithstanding this loss we find Mr. E. Cox Walker in the *Northern Echo* of England, in 1887, agitating at hreepenny rate with the same old arguments that had been used prior to 1870 and 1885, to inflame the public mind. I quote as follows, "There cannot be any doubt in any one's mind as to the enormous increase that would take place and the benefits that would arise therefrom to the commercial world, which is really the great user of this mode of communication. The cost of transmitting messages will of course be greatly reduced, as regards each message, by the full use made of all the instruments and wires. Then the carrying capacity of the wires is being greatly increased by the substitution of copper for iron wires, and the speed of signals has been wonderfully increased during the last year or two; news being now sent at the rate of 450 words per minute between London and Ireland and elsewhere."

On May 13th, 1892, a large deputation from the associated Chambers of Commerce waited on the Postmaster General urging the reduction of rates by allowing addresses to go free, notwithstanding the deficit for the last year was nearly two million dollars, with probably the post office bearing on its own account a large share of expense for use of offices, light, fuel, and services, that should have been borne by the telegraph service, the deficit has been yearly increasing up to the present time. The traffic in 1885 was about 100,000 telegrams of 16 words, a day.

To transmit these messages there were in the London central station 130 single sets of Wheatstone, each set of which was, or could have been, duplexed, and capable of transmitting on the longest circuits out of London 462 words each way or a total of 831,600 sixteen word messages to and from London during eight hours every day, or a grand total of nearly 2½ million messages per day operated continuously for the 24 hours.

Besides the Wheatstone automatic there were quadruplex,

duplex, and single circuits, aggregating 1100 circuits, capable of actual not theoretical, Morse transmission each one at the rate of over 70 sixteen word messages per hour, or a total of 528,000 messages in 8 hours.

Thirty English newspapers have special Morse wires and operators from 6 P. M. to 6 A. M. and the *Scotsman*, *Newcastle Chronicle*, *Manchester Guardian*, and some others had two wires each for news from London. It is highly absurd to suppose that because the Wheatstone system did not transmit at the rate of 1000 or more words per minute that 130 sets in London in 1887 were employed to transmit only about 1,000,000 words of press per day, when those sets had the capacity to transmit in eight hours 16,348,800 words "single" or 32,697,600 words "duplex" at the rate of 262 words per minute per set in either direction.

It is also equally as absurd to suppose that the purchase and use by the British government of the Stearns duplex, the Edison quadruplex and the Delany synchronous multiplex—all Morse systems—was due to the fact that the Wheatstone was not in itself fast enough. That the latter system would work at the speed hereinbefore stated we have unimpeachable evidence, and that its failure was not due to imperfect work is also well authenticated.

In Preece & Sivewright's work on the telegraph (1891) page 163 is as follows:

"Automatic instruments are employed on nearly all long circuits in England, not only because they increase the capacity of wires for the conveyance of messages, but because they are so specially adapted for the conveyance of news, which is such a distinctive feature of the English system of telegraphy. One batch of news is often sent to a great many different places, and as many as four or even eight slips can be prepared at one operation, and one slip can be used several times, the labor of preparing for transmission is very much reduced. It is of course evident that apart from its *extreme accuracy* the chief value of the automatic system is its increased speed of working."

In the United States the subject of fast speed telegraphy very early attracted attention, and here, as in England, it was then concluded that once a system was devised to carry several hundreds of words per minute over a wire, that a great revolution in telegraphy would follow, as will be seen by the following editorial in the *Telegrapher* of June 26th, 1869.

"We have heretofore stated repeatedly that we could see no way in which the popular demand for a material reduction of tolls could be met except by greatly increasing the transmitting capacity of the wires by automatic telegraphing, by which the practically instantaneous transmission of the electrical impulse may be made available."

Another editorial in the same journal, January 1st, 1870, says, "In connection with the question of a material and permanent

reduction of the charges for telegraphic service we have consistently argued that such reduction was only possible through a very great increase in the capacity of the instruments used for transmitting communications. Further observation and reflection has confirmed this opinion, any attempt otherwise to establish cheap rates notwithstanding the one-sided argument of Washburn, Gratz Brown, Gardiner Hubbard, and other advocates of low charges, and postal telegraphs, must result in loss to whoever undertakes the work whether it be a corporation or the government."

"To successfully accomplish such an increase of capacity as is essential to a material and permanent reduction of charges for telegraphic service, the invention of a reliable automatic system is indispensable."

In 1870 a line with one wire was put up between Washington and New York by D. H. Craig and others, for the purpose of developing the automatic system of Mr. George Little, and experiments were made at great expense until 1872 when offices were opened in December of that year in New York, Philadelphia and Washington for public business.

The subject about this time appeared in a new and more practical light to the editor of the *Telegrapher*, as evidenced by an editorial inspired by our late Past President F. L. Pope on June 15th, 1872, referring to the Craig-Little system as follows:

"While the columns of the *Telegrapher* have at all times been open to the fullest and freest discussion of automatic telegraphy, we have abstained from engaging in such discussion editorially because we did not care to prejudge an experiment which was being conducted energetically and with great liberality of expenditure by the parties in charge."

"We have been aware that in experimental trials very wonderful results have been obtained. We have never doubted the practicability of transmitting signals over the wires within certain limits of distance, at any desired rate of speed. The principle difficulties and obstacles encountered in automatic telegraphy *are not* in the *transmission* of the signals; they are in the *preparation* of the slips and in the *translation* and *preparation* of the dispatch for *delivery* when they have reached their destination, the practical limit of speed must always be, not what can be *transmitted* over the wires in an hour, but what *can be prepared* for *transmission* and *delivery*.

To show to what perfection the Craig-Little system had arrived, I will quote from a letter of Craig to the editor of the *Telegrapher* dated Washington, September 10th, 1870.

"A year ago, I bespoke your favorable consideration of a new telegraph enterprise which I had then fully entered upon, and which it gives me great pleasure to inform you has now been consummated in the completion of a very *superior* line of telegraph of compound wire, steel and copper, and the perfecting of

of our new system of automatic telegraphy by means of which we are now transmitting from this city to New York and vice versa, 500 words per minute over one wire, a rate of speed equal to the average speed of more than 50 wires by the Morse system. The perfect simplicity, accuracy and reliability of the new system is not less remarkable than the wonderful speed above stated."

"We can by our new system transmit intelligence direct and with one writing from this city to every other city and directly into the editorial rooms of every journal in the country at the rate of 500 words per minute recording the same in clear, distinct, and perfectly accurate characters."

In September, 1870, the President of the Western Union Telegraph Company challenged Craig for $1,000 to transmit a message of 2,000 words from Washington to New York under the following conditions.

"The Western Union will use but one wire and employ but two operators—one at each end—who will not be changed or relieved during the trial." Mr. Craig shall be allowed six operators—three at Washington to prepare and transmit, and three at New York to receive translate and copy the dispatch; and whichever party transmits, makes three legible copies and first delivers them at the offices of the *Herald*, *World* and *Tribune* respectively, shall receive the $2,000. The Western Union will place at Craig's disposal two extra wires so arranged that one of them may be substituted for his own in a few seconds."

This challenge was never accepted. Craig, however, made an evasive one on September 3, 1870, that the President of the Western Union Telegraph Company should join him in depositing $10,000 with some acceptable party and if after twelve months and for five years thereafter Craig did not earn and pay to his stockholders 10 per cent. of the dividends, for every one per cent. that may be earned and paid by the Western Union, it could claim Craig's deposit."

On January 7th, 1871, George Little, the inventor, published in the *Telegrapher* a statement that it was a fact that 2,000 or more words per minute could be transmitted over a No. 8 iron wire 250 miles long.

On February 3, 1872, an adverse critic in the *Telegrapher* states:

"On the 27th of September, 1870, a dispatch of 566 words was sent from Washington to Buffalo, dropping copies at New York and Albany in one minute and twenty-eight seconds being at the rate of 386 words per minute in a circuit of about 750 miles."

On June 5th, 1872, Craig states in a letter to the *Telegrapher* "between August and November, 1870, we telegraphed by our automatic system over our single wire between Washington and New York more than 60,000 words per hour, and recorded the

same accurately in clear black telegraph characters," also that he had perfected, perforating machines and typewriters, also a less rapid perforator which can be worked at sight by a child and is capable of perforating 30 words a minute, to be used by business men in way offices on side lines, and under date December 23d, 1872, he wrote to the editor of the *Telegrapher* claiming that all Craig's prophesies were met, and that he had a perforator by which one operator could do over 100 words per minute, also that he could transmit and record over one wire over 300 miles long and by the aid of two girls 1,500 words per minute in good or bad weather and could transmit more matter over a single wire and by the aid of two girls than the Western Union Telegraph Company could transmit over 60 of its Morse wires with the aid of 120 high salaried operators.

This was asserted over 18 years ago, and yet the Morse operators flourish, and are to-day working by Morse system the very wires that figured so seriously from that time to the present in quixotic automatics.

In December, 1873, it was stated that the President's message of about 12,000 words had been punched and was transmitted from Washington to New York in about 20 minutes in the presence of notable government officials.

Taking Craig's lowest speed of 500 words per minute, between Washington and New York, it is easily figured that his system could transmit 8,000 messages of 30 words each in 8 hours, while the best the Western Union Telegraph Company was doing upon its entire system, embracing 137,199 miles of wire was 40,000 30-word messages per day of 24 hours.

This Craig and Little system expired from natural causes in the arms of the Atlantic and Pacific Telegraph Company in 1875. Craig in 1879 organized another machine telegraph system and started the American Rapid Telegraph Company which put about two million dollars cash in a very extensive plant with compound copper coated wires between New York, and Boston, Philadelphia, Baltimore, Washington, Pittsburg, Albany, Buffalo, Cleveland and intermediate places. The very best mechanicians and telegraph electricians were employed, and between New York and Boston 500 words per minute could be transmitted and recorded with perfect legibility. The new system was in a high state of efficiency, its operators and clerks were highly skilled. Anderson keyboard perforators were used, and all copies were made upon typewriting machines. In a test for eight days April 5th to April 15th inclusive, 1884, 3131 ordinary telegrams were transmitted between New York and Boston occupying 30 hours and 46 minutes, or at the rate of 104 30-word messages per hour or 52 words per minute.

The American Rapid Telegraph Co. was cocksure of effecting the revolution in telegraphy predicted by Craig, and with great confidence had reduced the rate to 15 cents for twenty words,

addresses and signatures free, but it was soon found that the telegraphing public would not patronize the automatic system on account of its slowness in delivering messages, and Morse sounders were necessary to secure any business from a public only too anxious to favor competition. The "Rapid" system involved its promoters in financial disaster, and was entirely abandoned in July, 1884, as I know personally for the foregoing reasons, and not from its inability to record the electric signals fast enough, as it would record legibly 1,000 words per minute between New York and Boston.

The Postal Telegraph-Cable Company started the Leggo automatic system in 1881 upon two electro-copper-deposited steel wires New York to St. Louis via Chicago, two New York to Washington, two Buffalo to Pittsburg, including all the heavy commercial cities of this country. These wires had a resistance of $1\frac{7}{10}$ ohms per mile and isolated from all other wires. These wires have never been equaled the world over. Rates were reduced, as it was a foregone conclusion with the promoters, that an automatic system that would carry over 1000 words and record them in a thoroughly reliable manner, between New York and Chicago, (which the Leggo system did) and which needed no complicated perforating machines, would not only attract all the Western Union traffic between these points but would also to a large extent empty the mail bags. After the stocks and bonds had been floated and hundreds of thousands of dollars expended for machinery, it was found that sufficient business could not be secured unless it was transmitted by the Morse system, and at the low rates established, it would be done at a great loss with such a limited number of wires, so another expensive bubble, including the company, burst.

In 1883 the Western Union Company introduced the Wheatstone system from England, although perfectly well aware of the speed of the automatic system that had been perfected in the United States. It was found that the Wheatstone system could only be employed as an adjunct to the Morse, and but eight Wheatstone circuits were put in operation and to these was assigned a class of slow freight business. In cases where it was attempted to do a general business between commercial cities the public would withdraw its business in favor of a Morse transmission. After the lapse of fifteen years, only six Wheatstone circuits are being operated by the Western Union Telegraph Company. They are all duplexed and have a total actual regular working speed both ways of 1600 words per minute. Upon the basis of computation usually resorted to by automatic advocates it is easy to see that about 70 such circuits in use only 10 hours of every week-day, will carry all the business of the Western Union Telegraph Company.

In referring to the *Telegraph Age* of December 16th, 1894, we find a record of a test made Oct. 16th, 1893, of the Wheat-

stone upon a Western Union wire having a carrying capacity of 400 words per minute both ways between New York and Chicago (972 miles) between 9 A. M. and 5.30 P. M. a total of 5563 regular messages were transmitted at the rate of 654½ per hour or 327 words per minute.

It required 27 punchers, 22 copyists, 4 clerks, and two electrical engineers or a total of 55 persons making 13½ messages per hour per operator.

The punchers at their best speed averaged 24 messages per hour, the copyists 30; average delay on each message in New York was 15 minutes, in Chicago 16 minutes.

This test was during the World's Fair and a highly trained corps of operators was keyed up to its highest pitch to obtain results that would astonish the foreign representatives.

On December 21st, 1896, on a postal duplex Morse circuit between New York and Pittsburg there were 341 regular messages containing 10,216 words received at New York in 5 hours or 68½ messages per operator per hour, and two hundred messages containing 5605 words received in Pittsburg in 3 hours or 66⅔ messages per operator per hour, or a total of 135 messages per hour for two sending and two receiving operators or about 34 messages per operator per hour as against 13½ by the above Wheatstone test.

Thus 19¼ Morse operators could have accomplished on two quadruplexed wires, and one duplexed wire, as much as the 53 skilled persons accomplished in the before mentioned Western Union Wheatstone test.

In 1891 *La Lumiere Electrique* published a statement that in the daily operation of the French government telegraphs, the Wheatstone averaged a total of 200 messages per hour at the rate of 11 messages per operator per hour, and the Morse quadruplex 160 per hour or 20 messages per operator per hour.

The Morse sounder system is far and away the simplest and most accurate of all methods of telegraph transmission, for the reason that the sending operator need not remove his eyes from the matter that is passing out at the ends of his fingers, via the key, to the distant station, and there is not the slightest mental effort necessary to secure a ready response of the key to the necessary dots and dashes that represent the words and letters of the message; and likewise at the distant end, the eyes of the receiving operator do not move away from the keyboard of the typewriter, or the page traversed by the pen, as the hands respond without mental effort to the sounds impressed upon the ear. Not so with any automatic system (excepting perhaps the Leggo to the extent of preparing the messages) that has ever been proposed. The eyes must constantly be in rapid motion between the copy being prepared for transmission, and the machine that punches or prepares it, and in this case the eyes are very apt in returning to the matter, to fall upon the wrong letter,

word, or line, or get confused and blurred from an infinite number of excursions hourly, and thus errors unconsciously creep in, besides a slowing down of the human action. The same is true in a more marked degree as to the copying from the automatic record. The eyes of the copyist have to fly back and forward between the keyboard of the typewriter and the record upon the tape and are subject to the same liability of aberration as in the preparation.

In a public address by M. J. Banneux, Chief Engineer of the Belgian postal telegraphs, he said that the Cook and Wheatstone needles that were first introduced in Belgium had been supplanted by the Morse system which was destined to progressively dethrone every other, as it was the acme of simplicity.

In my opinion the grade of skill necessary to successfully operate an automatic system is as high, if not higher than the skill required for the same class of business by Morse, the wear and tear per message upon the automatic operator being greater. The floor space necessary in an operating room to accomodate an automatic system would require to be quite double that for Morse of equal capacity to handle the traffic expeditiously before and after transmission, a very serious matter in large cities.

The automatic system involves the consumption of large quanties of very expensive and special paper for both preparing and recording, not required by the Morse, and the first cost of maintenance and management of automatic machinery for all known or proposed systems is much greater than for Morse.

The difficulty of securing prompt explanation or corrections between automatic stations has been a most serious drawback.

The Wheatstone electro-magnetic recorder survives all the faster chemical systems, because it preserves a permanent ink record, and possesses a greater working margin upon the wires under existing conditions, and is capable of being worked duplex.

There will be large loss of wages through the idleness of employes during an interruption to the wires from storms or other causes upon an automatic system normally worked to full capacity.

Mr. Craig, in his pamphlet on machine telegraphy August, 1888, among other things that he had dressed up in his most attractive style to allure capitalists or the government to buy his system, advocated the use of his keyboard perforators, by patrons of the new system, to prepare their own messages, and send them to the general telegraph office, where they would be transmitted at the rate of from 500 to 2,000 words per minute, and if their correspondents' clerks or typewriters at the distant city can translate the telegraphic characters, the slips would be directly delivered to such correspondents and the cost would be but little more than the government would charge for a specially delivered letter.

This is the most attractive feature that so far as has been urged by the advocates of automatic telegraphy, and it has appealed powerfully to both the non-technical public and to those paternal members of the government and congress who seem to think that the public greatly needs to have its letters carried by telegraph, and that a machine that will shoot 3,000 words per minute will accomplish the object at nearly postage rates. Here we are compelled to depart from the results of experience, to probabilities founded upon experience.

A large merchant in attempting to carry out Craig's plan would need a combined perforating machine and typewriter so that the letter-message being copied from the stenographer's notes for telegrapic transmission would be simultaneously prepared on the automatic slip and copied by the typewriter for the files, and also for the patron to see what he was sending away. Every error of the clerk in copying from the stenographer's notes or in striking wrong keys, would necessitate cutting and patching the automatic tape or leaving it with a jumbled up mess of errors and corrections to go over the wire. The clerk must be as highly trained as Wheatstone punchers with years of daily training in order to copy 720 words per hour on an average of messages averaging 30 words each, and at this rate the shorthand characters must be as readable as the writing in ordinary messages.

The prepared tapes must be upon reels ready for the transmitter, and sent to the central station by letter carrier or messenger, and it is not likely that important messages would merely be thrown in the reel receptacle at such station with thousands of reels from various firms. Each reel must have an address upon it so the central station could tell where to send the message, and only messages for one place could go on one reel.

The distant central station must have clerks to decipher the addresses of every message upon the tapes and place those for each person or firm on a separate reel properly addressed. These reels are delivered to the proper parties by letter carrier, and clerks are set to work to translate the characters into English upon the typewriter which can be done at an average of 900 words per hour by a clerk equally as skilled as a first class Wheatstone copyist trained by years of practice, provided the characters on the tapes were as easily deciphered as those employed on Wheatstone. If patrons desired to maintain secrecy by the use of a cipher code it would slow down the work many times, as any practical mind will readily understand.

The machines used to prepare and record the messages in the sender's office would be very complicated and costly, not less if made in large lots than $150 to $200 each, and a patron doing a large business would need several of them, together with high priced clerks to operate them, and in his correspondent's office at the receiving end one clerk would be required for every 900

words per hour to translate and copy the morning telegraphic mail, to say nothing of the desultory reels that would arrive during the day.

In the event of an interruption to the wires during the night, the messages would encroach upon the day service and cause great confusion. Of course when long letters were transmitted, the above rates of preparing and copying could perhaps be doubled in the case of highly trained clerks, but taking the thick with the thin, the figures given I am convinced would be found in actual practice to be too high, just as no telegraph company at present realizes a daily average transmission of 98 30-word messages per hour per sending operator upon the busiest circuits.

It is obvious that the central stations could not keep a lot of idle clerks and machines to come to the rescue of the patrons to take care of irregular matter or to fill in the absence of their sick or tardy clerks.

Increasing the means of quickening and cheapening the transmission of messages is not followed by a general and proportional increase in their number. This is the experience of all countries including England where the governments have assumed to do the business at low rates. Any large increase to the number of messages transmitted under the stimulation of lower rates has been found to pertain to the regular class of commercial institutions and firms of the country and the newspapers that do the great bulk of telegraphing.

It is very uncertain to what extent the public would withdraw communications from the mail and transmit them by telegraph. I do not believe the amount would be very considerable, even if the telegraph processes were such as to admit of extremely low tolls, as letters are absolutely confidential and are largely in such shape for account and record purposes that no electrical transmission and reproduction is possible.

To sum up I think it has been shown that there is a traffic limit to the availibility of an automatic system of about 163 words per minute for ordinary telegrams in one direction; that it will cost over twice as much to prepare a given number of ordinary telegrams for automatic transmission as it will to send them by Morse, and it will cost over twice as much to record them on the typewriter by automatic than by Morse, provided the operators are paid according to their respective grade of skill.

Inasmuch as commercial exchanges and large business concerns insist on quick delivery during the business hours of the day, the use of any automatic system for such traffic has been absolutely out of the question. The public demands for prompt transmission has compelled a constant increase of Morse wires worked either single, duplex or quadruplex, which during the night afford more carrying capacity by Morse method than it is possible to get

business to fill at remunerative rates. The cost of managers, chief operators, operators and clerks is about 44 per cent. of the total expense of transacting a general telegraph business, under the most economical management. So that if it were possible to prepare transmit by automatic system and copy for delivery during the night, large batches of mailable matter at a price that would about pay for such preparation and delivery, the tolls for the commercial day work would have to be high enough to bear the entire 56 per cent. general expense of the whole telegraph system besides depreciation and interest on investment.

Dr. A. E. Kennelly:—The question of rapid telegraphy has two aspects, the engineering and the commercial. I suppose that we may assume as a purely engineering problem, that any desired speed over a thousand mile circuit can be attained up to 2,000 words per minute, provided that expense is no object. That is twice as high as the speed which Mr. Jones tells us has actually been reached between New York and Chicago. The paper before us suggests a particular means of carrying out a speed such as this, viz., a method based upon the use of an automatic current transmitter, with special tape and contact devices, and also upon the use of a special form of receiver. I do not think that the particular kind of transmitter and receiver suggested in the paper is of any consequence to the general problem. In the first place, it is not necessary, so far as I can see, to employ an alternating-current transmitter. That is only one form out of a number of forms that have been devised. It is not necessary to employ a photographic device of the type described, because that is a difficult instrument to handle and it must evidently require considerable skill. Moreover, I should suppose it would place a large amount of inductance in the receiving instrument. In such work as I have done on apparatus employing polarized light, I have generally found that a large amount of magnetic force was required, a great number of ampere-turns, and that suggests a high inductance at the very worst place in a high-speed circuit to receive it, namely, at the receiving terminal. Still it is interesting to see that the authors have been able to secure records of very high speeds, and as an experimental investigation it is, no doubt, a very interesting matter, though as regards actual practical telegraphy I should think that some modification of the Bain instrument would be very much simpler to construct, operate and introduce.

The commercial question is, of course, the one which controls in this matter. If you have a very high rate per word you will, of course, have a very small number of messages. If your rate is, say, a cent per word, then it is a matter of general experience, that if you make the rate just one-half a cent per word, you will not get, at the outset at least, double the traffic, no matter what it has cost you to improve the system to accomodate the increase of traffic. That has been true in cable and in land telegraphy.

I do not say that you will not ultimately get the increased traffic —I think you will—but in the meantime, while the experiment is being performed, you have to face a loss of income. At the present rates of telegraphy only important communications can be commercially sent. We do not send letters that way because it would be too expensive. I do not think there would be any doubt, if we got in the habit of writing our letters by telegraph, that the telegraph people would eventually find means to handle the traffic which would result. I do not believe that they would continue to do so, in that event, by merely reduplicating Morse circuits. I do not doubt that when they had to handle many times the traffic that they have now they would continue to handle it by other means than by the ordinary Morse system. A time would come when the reduplication of Morse circuits and operators would be so great that they would find it to their advantage to introduce an automatic system. Just when that time will come, of course, I cannot say. It has been the experience hitherto that when the traffic exceeds a certain rate, the Morse system has been unable to deal with the traffic, and an automatic system has been adopted. The automatic system used has been the Wheatstone system. If the traffic were again increased in corresponding ratio, however, even the Wheatstone would be unable, no doubt, to meet the demand, and a still more rapid system would be called into existence. But I still believe that if the necessity existed, that if we were accustomed to send our mail through the wires, the telegraphic system would readjust itself so as to handle the business. Commercially, the telegraph system might at first be placed at a considerable loss, because the public would have to do their own punching and translation, and this education of the public is a slow and expensive process. Whether we shall see it in the future is a matter which only the future can tell. It is a grand possibility that we could send our letters to a telegraph office and get them sent over the wires instead of waiting for the locomotive to carry them. It is only a question of time and commercial necessity when it shall become accomplished.

Mr. P. B. Delany: It is always interesting to a telegrapher to hear from Mr. Jones, especially in a historical way. His resumè of the telegraph is always very entertaining. I presume from his standpoint of a Morse telegrapher that he aims to be perfectly just and fair. Before referring to the paper which is up for discussion I would like to review in a very brief way some of the statements advanced by Mr. Jones regarding the telegraph both from a practical and a commercial standpoint. He goes back to 1857 and the 60's, and quotes the Bain system in its state of development at that period as an evidence that there is no necessity at the present time for machine telegraphy. Everybody who has studied the subject must know that at the beginning of Bain's experiments the chemical paper which he

used for recording was evanescent, and would fade out in a few moments, that his perforating machine and all his apparatus was very crude and that in almost every respect his plan was practically inoperative.

To prove that good automatics have no more show than poor ones, Mr. Jones then goes to the Wheatstone system and does it certainly full justice in regard to its merits of speed. I have watched the Wheatstone system in England personally for a long time, and, while the speed Mr. Jones refers to may be obtained on special occasions and under special conditions, I am prepared to state that in its practical operation it falls at least fifty per cent. below the speed he has ascribed to it. As to the accuracy of the Wheatstone system or of automatic telegraphy in general he rather impugns it, and says that it is not as correct and reliable as sound reading. I would remind Mr. Jones that where speed is not the main consideration, as, for instance, in cable telegraphy, the Wheatstone system is used and preferred on account of its accuracy. There is no class of telegraphy that requires the same degree of accuracy, or makes a greater demand upon reliable and capable operators, owing to the fact that the messages are composed almost exclusively of code words or of cipher, having no text to guide the operator, the alphabet being as it were, thrown together promiscuously like pied type. In every instance, with the exception of three cables crossing the Atlantic, out of the eleven that are in operation, the Wheatstone system or some system similar to it, with slight modification, is used, and yet with the exception of one or two cables, operators are able to transmit as fast by hand as the cables will take it, but nevertheless the Wheatstone system is used because of its uniformity in signaling to which higher speed is incidental. Even the business transmitted from London to the cable stations is sent by the Wheatstone system. And as regards the difficulties of translation from the tape, compared to the ease with which translation is made from a sounder to which Mr. Jones refers, the leading cable company, the Anglo-American, punches the messages from the received Wheatstone tape at Valencia without any intermediate translation by typewriter or manuscript. Having spent several weeks at the latter station conducting some experiments I had ample opportunity to study the operations of this system under most trying circumstances, and was informed by the operators that they would much prefer to compose messages on the tape or re-transmit by hand into the cable from a Wheatstone tape, than from the manuscript of their brother operators.

Now as regards the post office business in England, and the deficit which Mr. Jones says accumulates from year to year, it is well understood in England at least that the post offices and telegraph department do not agree in regard to the manner in which the accounts of the two departments are kept. But assuming

that the post office department did justice to the telegraph department, Mr. Jones neglected to state that there is a large volume of railway business—I will not state what proportion it bears to the whole—but I might venture to state that it represents at least five or six per cent. in value which goes free. And furthermore that the charge of one shilling for 75 words during the day, and 100 words for a shilling at night and twopence for drop press messages, is only made possible by the use of the Wheatstone system, and, if the rate charged for press work in England approximated the charge in America, together with the free railway business, if it was charged for, the British telegraph whold be self-sustaining if not profitable.

Mr. Jones next comes to automatic telegraphy in America. I was connected with the experiment between Washington and New York that he refers to, and 500 words a minute were transmitted. We thought at that time and we were justified, considering the state of the art, that the signals were very good, especially in face of the fact that the then electrician of the Western Union Telegraph Company staked his reputation on the statement that it was impossible to send more than 60 words a minute over, I think, 100 miles of line. Mr. Jones with his experience certainly understands that improvements or innovations, as you might call them, have never been welcomed by the controlling telegraph company, that the duplex had a long battle before it was adopted by the Western Union Telegraph Company, and its inventor had to create an opposition telegraph line for the purpose of forcing it upon their notice; that the quadruplex system of which he speaks so favorably, even after the Western Union took it over, was held in abeyance for weeks until the managers of the company told the operators that unless they worked the system they would get others who would, that is, in other words, if they did not *make* it work and lay aside their prejudices they would be dismissed. That is the history of the quadruplex system, and yet according to a statement of the president of the Western Union Telegraph Company, five or six years ago, if the artificial circuits created by the quadruplex system had to be reproduced in the actual wires, or the facilities that they afforded had to be duplicated, it would cost the company eleven or twelve million dollars.

Coming back to the automatic system of the original automatic company in this country, Mr. Jones says it lived its natural course and then died. I know what became of that company. A telegraph magnate of the time paid one man connected with it who had a basis or foundation patent in his own name, and unassigned to the company $120,000 for it, after having agreed to pay the automatic company about $3,000,000 for the system, which he failed to do, and that same system was turned over to the Atlantic and Pacific Telegraph Company, or the Western Union Telegraph Company eventually, for between three and four mil-

lions of dollars. Not such a bad investment for a system that was not good. I am quite familiar with all of Mr. Craig's statements and claims for automatic telegraphy, and I think Mr. Jones will agree with me that no telegrapher in this country or any other ever accepted Mr. Craig, from whom he quotes so copiously, as a technical authority in telegraphic matters, nor did Mr. Craig claim it. The American Rapid Telegraph Company, which was the last automatic company in operation in this country, did an enormous business, which, if not profitable, was at least self-sustaining, which was a great deal in view of its limited ramification at the time. It was taken up by a Morse company, and, through stock manipulation in Wall street, swamped, its stock having dropped from $115 one day to $2 per share the next day.

Mr. Jones next refers to the use of the Wheatstone system in this country, and cites some speeds between here and Chicago, which are certainly very creditable to the system, and he puts against that work, speeds reached by the Morse system between here and Pittsburg. The Wheatsone system employs automatic repeaters between New York and Chicago, while Pittsburg by the Morse system is reached direct. The Morse operators for this demonstration were undoubtedly the most expert to be found in America, while it is a noted fact that the Wheatstone system in this country has, through the policy of the company using it, been largely handicapped by inefficient and ill-paid labor. It would have been fairer if Mr. Jones had given notice of a race and not chosen his own time and conditions.

In regard to automatic telegraphy in general, I admit that the present companies have all the facilities necessary to carry all the business they can get at the present rate with their slow hand methods of operation, but it does not follow from this that the lowering of the rate, so that four or five times the number of words could be sent for about one-half the price would not increase the business so as to render necessary an automatic system of telegraphy and yield very profitable returns.

I will not take the time of the meeting to go into an analysis of Mr. Jones's calculation regarding the difference in labor and the number of people employed in the two systems relatively. That I will do at some later day; but I will make this statement, and I think it can be substantiated: That an operator preparing a message on a tape perforator without any interruption from line or other causes, the operation being purely local, will maintain a speed averaging as high as the Morse operator will average sending by hand, and that an ordinary wire from New York to Philadelphia will deliver a perfect record of 3,000 words a minute, and that a one-ohm-per-mile line will deliver a perfect record of 1,000 words a minute between New York and Chicago, and that when these messages are received, type-writer operators will translate from the tape bearing these machine-made characters, unchanging in their characteristics, with

greater accuracy and speed than from their own notes, or about as readily as from print, and everybody knows that an ordinary typewriter operator will easily translate 35 to 40 words per minute. Now, in the case of the Morse receiver, using the typewriter he cannot translate from sound any faster than the Morse operator will send, and Mr. Jones I am sure will not say that any Morse operator can keep up a speed of 35 to 40 words a minute on a average all day. I consider that a typewriter translating from a tape of distinctly recorded characters is equal to two Morse receivers, and that in the operation of the automatic system one employe out of three is saved, from an economical standpoint. The introduction of perforators into business houses doing a large amount of business for the preparation of their own messages, and the translation of their messages at the distant end of the line is but a small feature of what is practicable in connection with machine telegraphy. It does not imply that the bulk of the business will be done in this way. The aim of an automatic telegraph company for carrying a large number of messages at a low rate is simply to take the place of the mail train. Messages may be sent to the central office in the city either by the post office or by special messenger. They are to be transmitted at a high rate of speed, and dropped into the post office at the distant station, typewritten, put in envelopes and stamped just as if they had come by mail. I cannot see from a commercial standpoint where the hardship is in being compelled to supply perforators and translators at the ends of a wire necessary to handle all the business the wire will carry. I should be very glad if I was in the business commercially to be able to make one wire keep 500 perforators and translators busy. It obviates great expense in the construction of the original plant, in the number of wires that you have to construct; in the size of the poles necessary to carry them; the difficulties of tree trimming, and so on. And, more than all, the entailed cost of maintenance, which amounts, I think, to about $4.00 per year per mile per wire, according to the best information on the subject, and when you consider that one wire worked at an automatic high speed is equal to 20 wire quadruplex, and 40 duplex and 80 to 100 simplex for long or short distances, it seems to me there is room for great economy, and, consequently room for a very low rate of transmission, so as to take from the mails a vast amount of business that now goes by the mail train. And yet the chief objection of the Morse men is that one wire can be made to keep so many operators going.

Mr. Jones makes a point of the delay. He says that in Chicago there is on an average a delay of 16 minutes and at New York a delay of 15 minutes by the Wheatsone system, making 31 mintes delay in the transmission of a telegram from New York to Chicago. Now, we have all had experience in telegraphy to the extent of paying for messages and having them sent and deliv-

ered. I venture to say that the average time of telegrams in this country, leaving out the business done between stock and other commercial exchanges, will average more than an hour. The telegraph companies in this country are very careful not to put on the message that you receive, the time at which it was filed at the point from which it started. They give you very plainly the time at which it was received at the office down the street. That is simply a tab on the messenger to see whether he stopped to play marbles on the way. But if you receive a telegram at six o'clock this evening from Philadelphia, there is nothing to show you that it was not filed there at nine-o'clock in the morning. If we take Mr. Jones's statement, messages are only a few minutes on the way, but every telegraph operator knows that messages accumulate and hang on the hooks for hours at a time, especially in the case of interruption to some of the wires, and that the traffic chief goes around and sorts them over perhaps a dozen times, picking out the more important ones to get them off first, so that if a man telegraphs his wife that he will be home to dinner at six o'clock they endeavor to get that message to his house a little before he arrives, while the wife of the man who says he won't be home till morning, sits up half the night waiting.

Now, if I may be permitted a few words in regard to the paper before the meeting. Prof. Crehore and Lieut. Squier advance the theory that much is to be gained from the use of the alternating current in telegraphy, and naturally enough I presume most people are inclined to accept that proposition. But, referring to the description, it seems to me that the object sought is not gained in the plan proposed, for the simple reason that if a half-wave, we will say, at any period, but taking it on the basis of 140 whole waves to the second, is eliminated for a dot, or for a space, two half-waves for a dash, and three half-waves for spaces between words, and so on, I am unable to see how by the elimination of half-a-wave or three half-waves you get the benefit of the alternation, because the next impulse that goes into the line is of the same polarity as the one preceding, and the line with its static capacity remains charged especially at the receiving end. It may be said that there is a drop in the potential to the zero point which possibly allows the line to clear itself to a certain extent, but I think no one will claim that the effect of that is of paramount consequence compared to the amount of current remaining in the distant end of line while this half-wave is being eliminated. Furthermore, unless absolute synchronism is maintained between the movement of the tape on the wheel under the transmitting brushes and the alternations of the current, the signals will be clipped or false signals sent, which would not be the case with a constant current. It may appear to be a very easy matter to some, to subject a tape to the preliminary operation of making a uniform row of guide

holes so that it may be pulled through a punching machine afterwards, which, by the operation of a star wheel fitting into these guide holes, will feed it absolutely correct for the composing of the dots and dashes on the tape by another operation. This does not appear to be a simple matter to me, and I have had some experience in that line; but assuming that it was easy to do, when this message is put on the wheel for transmission there must be some slack or else considerable tension on the strip to hold it in place, and the star wheel pulling the tape over the circuit wheel where the transmitting brushes rest, surely will have a tendency to pull it and spread the guide holes especially if the friction of the transmitting brushes is of any considerable amount, and if the friction is not sufficient to hold the tape it would be, I think, mechanically impossible to pull that tape at a high rate of speed so that the dots and dashes would conform accurately to the reversals of the current. Then there is the other very important consideration of the wheel becoming coated with dirt and not making a good contact. There is the difficulty also of making dashes with a perforator; such a machine would be altogether a very intricate affair. Thus far all efforts have failed to make a perforator of this kind, that would do its work accurately and reliably. The same objection of lack of true alternation of current applies in regard to the use of condensers, which I believe the paper states might be introduced in series in the line. The condensers would not be uniformly discharged.

Perhaps I do not understand the operation of the receiver proposed or contemplated in the paper. I presume that two pens must rest on top of the chemical paper, one connected to the line and one to the earth, and, as the currents are normally alternating, it must be that in the case of a dash, for instance, one portion of the dash will be formed on one line and the other portion on the other. As it takes a complete wave of the current, and as the record will be made in the negative, I think that such a record would be very difficult to translate. Furthermore, the tape would have to be placed on the transmitter, while the transmitter was at rest, and it would have to be fixed so that if there was to be any uniform relation between the signals as regards the character of the current that was to begin the message, it would have to be fixed very accurately on the star wheel that was going to pull it. Even then I am unable to see how signals could be depended upon for alignment. Take the letter *w* for instance. The dot of the letter would be on the top line, the half of the dash would be on the lower line, and the balance of the first dash would be on the top line again, and then another complete wave for the other dash would cause similar changes in position.

In regard to the speed claimed in the paper, I have no doubt that the computation, was the result of inexperience, when it states that the word "ten" may be transmitted 1,200 times in a minute.

The word "ten" is composed of four signals. A dash for the *t*, a dot for the *e*, and a dash and dot for the *n*. These four signals might be sent by the most economical use of perforations such as is used in another system with four impulses. The average number of impulses to a letter is about three. If you count the spaces between the letters, or between the component parts of a letter, it gives considerably more, and the average number of letters to the word in the English language is about five. So that the word "ten" comes to very little more than the impulses comprised in one letter; or, making all allowances, it seems to me that the speed reached or supposed to be possible in this arrangement would amount to about 300 words a minute instead of 1,200. According to the continental code there are in the alphabet 44 dots and 38 dashes. The paper proposes to allow the length of two dots for a dash. In the Wheatstone and other systems three lengths are allowed and I think practice will show that it is not too much. Now on that basis this system, compared with the strip using a single dot for a complete dash, as well as for a dot, or where all the signals are dots, it seems to me that the number of impulses required for the same amount of transmission would by this system be almost double.

Regarding the duplex and diplex extensions of this system, I am unable to grasp the solution advanced in the paper. I can understand that predetermined subdivisions of the circuit wheel might give off on electro-magnetic instruments of some kind operated synchronously different messages, but I do not see how it would be possible to have the division of this wheel predetermined by messages of undetermined arrangement of dots and dashes, and any of the currents used for lesser speeds must be of necessity, as I understand it—unless they are superposed, and I do not suppose that was intended here—be taken from the higher rate of speed, and the maximum rate of speed must be deteriorated in a corresponding degree. I cannot see how two messages can be simultaneously received on a chemical system, for the simple reason that all the impulses will manifest themselves on all the tapes of the receivers. (Applause.)

LIEUT. SQUIER:—I will only take a moment, as the hour is so late. It has been a pleasure to us who are inexperienced in business methods to hear what Mr. Jones has said this evening. The experience gained in actual practice is of course very much to be valued, and he seems to have succeeded in showing, I think, that from the beginning there was a desire to increase the capacity of lines; in other words, that the telegraph companies found that men at the ends of the lines were less expensive than wires. And I judge from the arguments that have been put forth that we have now about reached a point at which we have gotten all the speed that is desirable, and all the business can now be handled in the present way, and that, so far as we can draw from the data he gives, we have practically reached a limit in telegraphy. Mr.

Jones says that the telegraph companies can handle all the business now offered to them. This is probably true of the particular kind of business that the telegraph companies are now handling; but that is not the kind of business we were particularly considering in this paper. Undoubtedly Mr. A. will continue for some time to come to send his ten words to Mr. B. as at present, and the existing companies will continue to handle that kind of business. The business we were speaking of was more particularly telegraph letter writing—less urgent matter perhaps, but still, more so than ordinary letters—and this larger volume of business we think can only be handled by some form of automatic transmission. We know that plenty of people pay ten cents for a special delivery stamp so as to gain an hour perhaps in the delivery of a letter at its destination. Now that is just the kind of business that we are talking about—not the long letter of friendship or the ten word message, but the business letter which we desire to reach our correspondent in Chicago, for instance, not in fifteen minutes, but within two or three hours. That is the kind of business—the new business, that we were talking about. Therefore, the arguments that have been presented do not seem to me to hold, because the speakers have been talking about a kind of business that we do not propose to handle at the outset.

I am sorry that Dr. Kennelly should have gotten the idea that we require the use of a polarized receiver. We used it in our experiments because it was found convenient to investigate the properties of rapidly varying currents, and we did not propose it in a practical telegraph receiver at present, and so state in the paper. Dr. Kennelly also suggests that when the demand for such business arises, the telegraph companies will be able to handle it. The way to create that demand is to put down the rates so that business people can telegraph that kind of business. If the rates are kept as they are now, probably that demand will not arise, but I think if the rates were half what they are or even less than they are, the demand would be enough. So that it seems that the fact is that the people must be educated up to the service they are entitled to, and then the companies will be obliged to take care of the business as soon as the demand comes. The better way to do is to put the price down.

There has been very little discussion of the engineering side of the paper which we had hoped for, and there seems to be no question about the transmission of an adequate number of waves. We have several examples of this already accomplished in the Anderson and other systems, so that there is no question about the practicability, but we believe this particular system has elasticity and development not possessed by the others, and we are in hopes that this point will be more fully brought out as an engineering feature aside from its commercial side.

In regard to transmission of waves, it might be said that the

long distance telephone line which is now in practical operation is about as good an example of the transmission of waves as could be wished, and beside which the system we propose is of course very simple. When we can distinguish the voice between here and Chicago, this is an example of wave transmission which is much more complex than anything we have proposed.

In regard to diplexing the line and so on, which Mr. Delany says he does not understand, I think the paper when examined carefully, clearly shows how the punching should be done. Our experiments were actually carried out, and the diplexing and so on have actually been done. I might mention something that has only developed in the last few days. We never until a day or two ago used the cutting out process at definite intervals on currents of considerable volume, but we have just made some further experiments, in this direction and found that there is no trouble at all. In fact, on this circuit we used an alternating arc, and found it very convenient as a receiver, and I have a record here of messages sent through an alternating arc at the rate 280 alternations per second. The arc appears all right; nothing is happening to it, so far as the eye can see. Of course the alternations are so rapid that the eye would not notice them. I have here the records, which anyone can look at and see how perfect they are (Exhibiting). This was an ordinary street arc-lamp. I merely mention this to show an additional feature of the matter, that you can synchronously interrupt and suppress integral waves in circuits carrying considerable power, the current being in this experiment about ten amperes.

Dr. Albert C. Crehore:—The commercial interest in this subject is undoubtedly very great, and it is impossible to refrain from some remarks bearing upon that, but where any part of the physical portion of it is misunderstood, I very much desire to have that corrected. I want to speak particularly in regard to Mr. Delany's not understanding the use of the half wave. First, in regard to the alphabet. The one shown was only one of very many which can be used. It is hoped that some time later on we shall be able to give more definite information as to the particular form of machine, but the distinction between this alternating wave and the dot made by the direct current seems to lie in the fact that the electromotive force is not a constant degree, but is increasing. I do not mean to go into the complicated physical question at all, but it seems to me that all the objections that could be brought against it were answered by the first speaker in saying that these waves can be transmitted. I very much wish that Prof. Pupin, who has some knowledge of this from his own experiments, would add something to this discussion.

GUTHE ON MAGNETIZATION.

[COMMUNICATED AFTER ADJOURNMENT, BY J. STANFORD BROWN.]

This paper is very interesting. The chemical composition of steel for magnets, however, is perhaps of more practical importance than might be inferred from the paper, or even from the remarks added by Prof. Thomson.

The use to which magnets are put, largely, or you may say entirely, determines the required chemical composition. Steel for permanent magnets will be entirely different from that for electro-magnets. Magnets made to sustain a load are satisfactorily made from a steel which would fail utterly for the controlling magnets of our beautiful Thomson wattmeters, and so on.

The following specification for magnet steel was a few days since submitted to the writer:—

C .75; *W* 4.5 to 5.5; *P* .03; *S* .02; *Si* .10 or less; *Mn* .12 or less.

Such steel is somewhat difficult to make and is consequently expensive, retailing at 40 cents or more per pound, according to quantity. The specification is peculiarly low in *C* for the amount of *W*. With so high *W* the carbon could more usually run from .95 to 1.05.

A highly satisfactory magnet steel for certain uses runs: *C* .65; *Mn* .35; *W* 2.95. On the other hand, for another kind of magnets, *C* .65; *Mn* .60; *W* nil; *Si* .25, and *P* .065 is supplied. Here the high *Si* is noticeable. Sometimes crucible steel is used, and other times a cheap open hearth steel seems to answer. The electrical companies have an enormous amount of data and know thoroughly what they want, but unfortunately they still seem to regard it of too high commercial value to be contributed to the advancement of science and their competitors.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 18th, 1897.

The annual business meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 4 P. M.

The following associate members were elected at the meeting of the Executive Committee in the afternoon.

Name.	Address.	Endorsers.
BANKS, WILLIAM C.	Electrician, Gordon-Burnham Battery Co., 83 West Broadway, New York City.	Geo. T. Hanchett. Chas. D. Shain. E. V. Baillard.
CLEMENT, EDWARD C.	Ass't Examiner, Electrical Division, U. S. Patent Office, Washington, D. C.	S. D. Field. R. W. Pope. F. A. Pickernell.
DAVIDSON, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.	Jos. Wetzler. T. C. Martin. R. W. Pope.
DE REDON, CONSTANT	Consulting Engineer, 27 Thames St., New York City.	Max Osterberg. Wm. Maver, Jr. W. A. Anthony.
HOSMER, SIDNEY	Sup't Underground Cable Dep't, Boston Electric Light Co., Ames Bldg, Boston, Mass.	W. A. Anthony. W. R. C. Corson. I. H. Farnham.
KINSLEY, CARL	Teacher of Electrical Engineering, Washington University, St. Louis, Mo.	G. F. Durant. H. H. Sykes. Fred'k Bedell.
NEILSON, JOHN	Sup't of Interior Wiring Department, Larchmont Electric Co., Larchmont, N. Y.	F. A. Pattison. A. J. Farnsworth. R. W. Pope.
RICHEY, ALBERT S.	Electrician, Citizens' Street Railway Co, 403 W. Adams Street, Muncie, Ind.	H. B. Smith. C. P. Matthews. W. E. Goldsborough.

Total 8.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners May 17th, 1897.

NICHOLSON, WALTER W. General Supt. Central New York Telephone and Telegraph Co., Syracuse, N. Y.

RICHARDSON, ROBERT E. Electrical Engineer, Pierce and Richardson, 1409 Manhattan Bldg., Chicago, Ill.

ROSA, EDWARD B. Professor of Physics, Wesleyan University, Middletown, Conn.

Total 3.

The President appointed Dr. M. I. Pupin and George A. Hamilton as tellers, and William J. Hammer and Charles S. Bradley as Proxy Commitee.

The following reports of the Council and Treasurer were read and accepted.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE YEAR ENDING APRIL 30TH, 1897.

In accordance with the Constitution, the Council presents for the information of the INSTITUTE a report of its work during the past year.

Under the requirements of the laws of the State of New York, under which the INSTITUTE was incorporated in 1896, the presence of a majority of the Council is required at each meeting to form a quorum. In a national organization, as the INSTITUTE is, the geographical distribution of the members of Council is such, that it is difficult to secure a quorum, ten out of twenty-one being residents of cities at a distance from New York where the Headquarters are located. For this reason an Executive Committee of seven members was appointed in order to properly conduct the affairs of the INSTITUTE. Under this arrangement there have been held since the last report, ten meetings of the Executive Committee.

The necessity of fixing upon a standard of light, was brought to the attention of the INSTITUTE early in the year by representatives of different companies engaged in the electric lighting business, and also by the National Electric Light Association through Dr. Louis Bell, Chairman of a Special Committee appointed by that organization. The matter was referred to the INSTITUTE Committee on Units and Standards, and its report recommending a standard of intensity and method of measurement, was printed in the February 1897 issue of the Transactions.

The amount of $2,300 having been received for life memberships since the founding of the INSTITUTE, and used in the current expenditures, it was decided that the Treasurer set apart each year the sum of $500 to be invested in a compounded membership fund. As the net income of the past year will permit of this being done, the required amount may be set apart from the surplus.

In the course of the business of the INSTITUTE, certain transactions have been made through its office, which are strictly commercial, and have heretofore been accounted for in the yearly report of the Secretary. In order to separate these items more distinctly from the regular receipts and expenditures, the sum of $150 was transferred from the Treasurer to the Secretary for commercial purposes, which includes such matters as the buying and selling of electrotypes, badges, certificates, etc.

The lease of the rooms occupied by the INSTITUTE, at 26 Cortlandt Street, was renewed for another year, the quarters having proved convenient and accessible for home members as well as those visiting the city, and suitable for the holding of committee meetings.

At the March meeting of the Executive Committee, it was voted to hold the General Meeting of the INSTITUTE at Eliot, Me., beginning on July 26th, 1897.

The special Committee appointed last year for the preparation of a new design for the INSTITUTE badge, has fixed upon a design, and prepared a model which has been referred to this annual meeting for consideration.

The total membership at the close of last year's report was 1035, classified as follows:

Honorary Members	2
Members	333
Associate Members	700
Total	1035
Associate Members elected, May 1st, 1896, to April 30th, 1897	103
Total	1138

Resignations have been received during the year, and accepted from the following members as in good standing:

CHARLES E. CHINNOCK,	B. P. FLINT,
ADAMS D. CLAFLIN,	W. S. FRANKLIN,
WM. J. HISS, JR.,	W. H. PEIRCE,
WM. B. LESTER,	ROBERT WATSON,
GEO. W. STOCKLY,	S. W. ROESSLER,
EDMUND V. COX,	W. C. BRYANT,
W. D. MAC QUESTEN,	E. E. BARTLETT,
CHAS. W. SPICER,	A. S. KIMBALL,
S. P. DENISON,	L. A. McCARTHY.

Total resignations 18

There have been the following deaths during the year:

HENRY A. CRAIGIN,	SAMUEL C. PECK,
LEVI K. FULLER,	WILLIAM SHRADER,
W. T. M. MOTTRAM,	E. CARL BREITHAUPT,
M. B. LEONARD,	FRANK H. DORR,
H. L. LUFKIN,	

Total deaths 9

Dropped as delinquent	34	
Elections cancelled	3	
Elected, but not qualified	1	65
		1073

Leaving a total membership of 1073 on April 30th, 1897, (a net gain of 38), classified as follows:

Honorary Members	2
Members	350
Associate Members	721
	1073

A list of the members elected during the year accompanies this report. The names have already appeared in the TRANSACTIONS.

The reports of the Secretary and of the Treasurer, show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of receipts and expenses during the year.

SECRETARY'S BALANCE SHEET.

For The Fiscal Year Ending April 30, 1897.

Dr.		*Cr.*	
To balance from previous year	$ 20 20	By cash to Treasurer	$9,933 43
Receipts for the year	9,933 23		
	9,953 43		9,953 43

ITEMIZED STATEMENT OF RECEIPTS AND EXPENSES OF THE INSTITUTE.

For Fiscal Year Ending April 30, 1897.

General Account.

Receipts.		*Expenses.*	
Treasurer's Balance from previous year	$239 99	Repairs	$1 00
Secretary's " " " "	20 20	Notary	50
Entrance Fees	475 00	Chicago Meetings	23 15
Life Membership (Carl Hering)	100 00	Library	11 14
Past Dues	535 23	Ice	23 30
Current Dues	7,844 95	Commercial	186 96
Advance Dues	45 23	Laundry	8 25
Electrotypes Sold	35 04	Office Expenses	17 76
Transactions Sold	339 55	Office Fixtures	24 73
Transactions Subscriptions	103 40	Express	70 53
Advertising	88 50	Telegrams	3 39
Received for Binding Transactions	45 59	Stenography and Typewriting	787 10
" " Badges	41 00	Stationary and Miscellaneous Printing	530 57
" " Certificates	22 00	Postage	496 18
" " Congress-Book	27 85	Messenger Service	5 35
Reprints Vol. 4	136 00	Salary Account	2,708 33
Miscellaneous	3 89	Meeting Expenses	215 98
		Rent of Office and Auditorium	1,100 00
		Engraving and Electrotyping	200 60
		Publishing Transactions	2,412 29
		Paid for Badges	66 00
		Paid for Certificates	9 75
		Entrance Fee Returned	5 00
		Treasurer's Balance to next year	1,284 06
Total,	$10,193 42	Total,	$10,193 42

Commercial Department.

Receipts.		*Expenses.*	
Cash from Treasurer, Nov. 23, 1896	$150 00	Purchases	$25 32
Sales to May 1st	37 39	Balance Cash on Hand	162 07
	$187 39		$187 39

The outstanding current bills against the Institute, April 30, amounted to.. $463 55
Due the Institute and collectible probably..... 655 00

Property on hand according to inventory, May 1, 1897.

Office furniture and fittings	$212 48
Catalogue Type, Cases, etc.	259 75
Transactions on hand	2,803 50
Congress Books	784 50
Library	200 00
	$4,260 23

Of the above, there has been purchased during the year, office fittings

amounting to $24.73 and type and type cases for catalogue $259.75. The inventory has been made at a low valuation and does not include the Transactions of 1896.

TOTAL NET ASSETS.

Building Fund	$936 48
Treasurer's Balance, Mercantile Bank	1,284 06
Secretary's Commercial Fund	160 07
Property as per inventory	4,960 23
	$6,662 84

Respectfully submitted for the Council,

RALPH W. POPE,
Secretary.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 18th, 1897.

TREASURER'S REPORT.

FROM MAY 1, 1896 TO MAY 1, 1897.

GEORGE A. HAMILTON, TREASURER, in account with

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from May, 1896	$239 99	
Received from Secretary, May 1, 1896 to May 1, 1897	9,953 43	$10,193 42

Cr.

Payments from May 1st, 1896 to May 1, 1897, on warrants from Secretary, Nos. 760 to 878, inclusive	$8,909 36	
Balance to new account	1,284 06	$10,193 42
Balance on hand, General Fund, May 1, 1897		$1,284 06

BUILDING FUND.

Balance as per last report	$850 00	
Interest accrued to May 1, 1897, 3 per cent. to May 14, 1892 and 2 per cent. thereafter	106 48	$936 48

Cash book and warrants herewith for audit. Vouchers are in the hands of the Secretary, to whom they are returned for filing after payment.

GEORGE A. HAMILTON,
Treasurer.

New York, May 18th, 1897.

The discussion of the paper read at the meeting of April 21st was then taken up. [See page 129.]

At the conclusion of the discussion, the report of Committee on a new design for the INSTITUTE badge was brought before the meeting, in accordance with the action of the Executive Commit-

tee, which had referred it to the annual meeting for consideration. After a thorough discussion of the matter the design reported by the Committee was adopted. [See design on cover.]

The tellers then reported the result of the ballot for officers, which was as follows:

FOR PRESIDENT.

Total Number of Votes Cast..... 348

F. B. Crocker	328	D. C. Jackson	1
A. E. Kennelly	6	C. O. Mailloux	1
Thos. D. Lockwood	3	H. A. Rowland	1
E. L. Nichols	2	H. J. Ryan	1
Jos. Wetzler	2	F. J. Sprague	1
Carl Hering	1	C. P. Steinmetz	1

Total..... 348

FOR VICE-PRESIDENTS.

Total Vote Cast..... 1334

A. E. Kennelly	431	C. F. Brackett	1
D. C. Jackson	418	Louis Bell	1
C. S. Bradley	413	A. S. Brown	1
C. O. Mailloux	11	W. S. Barstow	1
W. D. Weaver	9	C. L. Cory	1
Nikola Tesla	5	F. B. Crocker	1
J. W. Lieb, Jr.	4	C. R. Cross	1
Frederick Bedell	3	Jas. Hamblet	1
Louis Duncan	3	W. E. Geyer	1
F. A. C. Perrine	3	John Langton	1
F. J. Sprague	3	T. C. Martin	1
Wm. Maver, Jr.	2	E. L. Nichols	1
H. J. Ryan	2	W. B. Potter	1
H. A. Rowland	2	W. D. Sargent	1
C. T. Hutchinson	2	L. B. Stillwell	1
B. J. Arnold	2	W. M. Stine	1
A. S. Kimball	2	B. F. Thomas	1
Brown Ayres	1	Jos. Wetzler	1

Total..... 1334

FOR MANAGERS.

Total Votes Cast..... 1755

Alexander Macfarlane	428	A. C. Crehore	2
Gano S. Dunn	408	O. T. Crosby	2
Herbert Laws Webb	406	Alex Dow	2
W. F. C. Hasson	399	H. W. Leonard	2
R. B. Owens	13	M. Levis	2
Samuel Sheldon	9	Wm. Maver, Jr.	2
M. I. Pupin	8	F. A. C. Perrine	2
W. J. Hammer	6	R. H. Pierce	2
A. A. Knudson	6	A. L. Rohrer	2
C. E. Emery	5	C. A Terry	2
Jos. Wetzler	4	C. F. Uebelacker	2
A. J. Wurts	4	E. G. Acheson	1
Louis Duncan	3	Brown Ayres	1
E. J. Houston	3	Wm. A. Anthony	1
C. P. Steinmetz	3	C. L. Buckingham	1
W. S. Barstow	2	J. B. Cahoon	1
F. Bedell	2	E. Caldwell	1

J. J. Carty	1	C. O. Mailloux	1
C. L. Clarke	1	L. B. Marks	1
W. R. C. Corson	1	A. L. Riker	1
Chas. Cuttriss	1	H. G. Riest	1
W. L. R. Emmet	1	E. E. Ries	1
C. C. Haskins	1	C. T. Rittenhouse	1
F. S. Holmes	1	H. J. Ryan	1
A. Hartwell	1	O. B. Shallenberger	1
F. S. Hunting	1	Nikola Tesla	1
D. C. Jackson	1	J. H. Vail	1
W. J. Jenks	1	C. H. Warner	1
S. J. Larned	1	Townsend Wolcott	1

Total.....1755.

FOR TREASURER.

Total Votes Cast.....348

G. A. Hamilton	346	Ralph W. Pope	1
W. J. Hammer	1		

Total.....348

FOR SECRETARY.

Total Votes Cast.....348

Ralph W. Pope.....348

President Duncan announced the result of the election, and appointed Mr. W. J. Hammer and Dr. M. I. Pupin a committee to escort the newly elected President to the Chair.

The following paper was then read by Dr. Alexander Macfarlane, discussion upon which was deferred until the General Meeting, July 26th.

The meeting then adjourned, the members reassembling at "The Arena," where the annual dinner was held, at which 92 members and guests were present.

A paper presented at the Annual Meeting of the American Institute of Electrical Engineers, New York, May 18th, 1897. President Duncan in the Chair.

THIS PAPER will be taken up for discussion at the General Meeting, July 26th-28th.

APPLICATION OF HYPERBOLIC ANALYSIS TO THE DISCHARGE OF A CONDENSER.

BY ALEXANDER MACFARLANE.

In recent years the theory of the discharge of an electric condenser has played a very important part in the advance of electrical science; for it served as the starting point of the experiments of Feddersen, Paalzow, Helmholz, Lodge, Hertz, and many others, which culminated in the demonstration of the existence and properties of electromagnetic waves. The theory of the discharge was first given by Lord Kelvin, then Professor William Thomson, in a paper on "Transient Electric Currents" published in the June number of the *Philosophical Magazine* for 1853. The application to the phenomenon of the principle of the conservation of energy leads to the differential equation

$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = 0 \qquad (1)$$

where R denotes the resistance and L the inductance of the circuit, and C the capacity of the condenser which is practically the capacity of the whole circuit. If $q = A\,e^{mt}$ be assumed as the solution of the equation, then m must be such that

$$A\,e^{mt}\left(m^2 + \frac{R}{L}m + \frac{1}{LC}\right) = 0$$

which reduces to

$$m^2 + 2\,a\,m + b = 0 \qquad (2)$$

where for brevity a is written for $\frac{R}{2L}$ and b for $\frac{1}{LC}$.

According to the theory of the quadratic equation, there are

two general cases separated by a transition case. If a^2 is greater than b; there are two real values of m, namely

$$-a+\sqrt{a^2-b} \text{ and } -a-\sqrt{a^2-b}.$$

If a^2 is less than b, there are two imaginary values of m, namely,

$$-a+\sqrt{-1}\sqrt{b-a^2} \text{ and } -a-\sqrt{-1}\sqrt{b-a^2}.$$

The transition or separating case is where $a^2=b$: then there is only one value for m, namely, what is common to the two general values.

The following are the solutions which are usually given of the differential equation. In the case of real roots

$$q=c_1 e^{-(a-\sqrt{a^2-b})t}+c_2 e^{-(a+\sqrt{a^2-b})t}; \quad (3)$$

in the case of imaginary roots,

$$q=c_1 e^{-(a-\sqrt{-1}\sqrt{b-a^2})t}+c_2 e^{-(a+\sqrt{-1}\sqrt{b-a^2})t}; \quad (4)$$

and in the transition case

$$q=e^{-at}(c_1+c_2 t). \quad (5)$$

In the imaginary case, the apparently impossible solution is reduced to the form

$$q=A e^{-at}\sin[\sqrt{(b-a^2)}\,t+\varphi] \quad (6)$$

which shows that the change in the condenser at any time is given by a sine wave of period $\frac{2\pi}{\sqrt{b-a^2}}$ and of amplitude which diminishes geometrically at the rate a.

As the limiting case separates the two complementary regions of the real and the imaginary, we expect that the real solution is also capable of reduction to a form analogous to (6) and exhibiting the function with equal clearness. We also expect the transition solution to be evident from the two general solutions; but when they are in the above forms, the transition is not evident. We observe that in the former general case the roots are treated as simple algebraic quantities, while in the latter general case they are treated as complex quantities. A complex quantity consists of two components, one of which is real and the other imaginary. If there is any thorough going analogy, it must be possible to treat the real roots also as a species of complex quantity.

A complex quantity $a+b\sqrt{-1}$ can be reduced to the form

$r\ (\cos\theta + \sqrt{-1}\sin\theta)$; for $r = \sqrt{a^2+b^2}$, $\cos\theta = \frac{a}{\sqrt{a^2+b^2}}$, $\sin\theta = \frac{b}{\sqrt{a^2+b^2}}$. If we enquire into the geometrical meaning of the $\sqrt{-1}$ here appearing, we shall find that it means a quadrant of turning round the axis perpendicular to the plane of reference. Let β denote that axis, then β^θ denotes an angle of θ radians round the axis β, and

$$\beta^\theta = \cos\theta + \sin\theta\ \overset{\text{II}}{\beta^2}.$$

Hence the ordinary complex quantities can be expressed in the form

$$r\,\beta^\theta = r\,(\cos\theta + \sin\theta\ \overset{\text{II}}{\beta^2}),$$

and they are simply coaxial quaternions, the axis being commonly left unspecified, as it is the same for all.

Let $s\,\beta^\varphi$ denote another complex quantity, than $r\,\beta^\theta \times s\,\beta^\varphi = rs\,\beta^{\theta+\varphi}$

$$= r\,s\,[\cos\theta\cos\varphi - \sin\theta\sin\varphi + (\cos\varphi\sin\theta + \cos\theta\sin\varphi)\ \overset{\text{II}}{\beta^2}).$$

Here the product is formed according to the theorem for the cosine and the sine of the sum of two circular angles. Now the circular trigonometry has its complete counterpart in the hyperbolic trigonometry; consequently we expect to find a hyperbolic complex number. This subject was investigated at length in "Papers on Space Analysis,"[1] which I published 1891 to 1894. In this paper I propose to show that by treating the real root as a hyperbolic complex quantity, equation (3) can be reduced in precisely the same way as equation (4).

The exponential expression for a circular angle x is $e^{\sqrt{-1}\,x}$, which expressed definitely is $e^{x\,\overset{\text{II}}{\beta^2}}$. By applying the exponential theorem, we obtain a series which breaks up into two parts, namely,

$$1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} +,$$

and

$$\sqrt{-1}\left[x - \frac{x^3}{3!} + \frac{x^5}{5!} - \right],$$

of which the former is the series for $\cos x$ and the latter the series for $\sin x$. Now because the terms of the sine series are all affected by the sign $\sqrt{-1}$, they do not add directly to the other

1. "The Imaginary of Algebra." *Proc.* A. A. A. S. vol. —, p. 50. Fundamental Theorems of Analysis, p. 23. Definitions of the Trigonometric Functions, p. 30. Principles of Elliptic and Hyperbolic Analysis, p. 17.

terms, but are geometrically compounded as forming a perpendicular component to the terms of the cosine series. We enquire for the analogous exponential expression for a hyperbolic angle x. Algebra furnishes none. It is not e^x, for

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} +$$

and here there is no ground for breaking up the series into two components; all the terms are real, and so add directly. For the same reason, it cannot be e^{-x}. But we know that

$$\cosh x = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} +,$$

$$\text{and } \sinh x = x + \frac{x^3}{3!} + \frac{x^5}{5!} + ;$$

there must therefore be some proper way of expressing the sum by an exponential function.

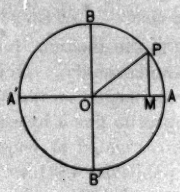


FIG. 1.

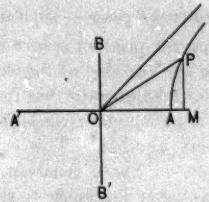


FIG. 2.

Before proceeding further, let us consider what is meant by a hyperbolic angle.

In Fig. 2, let A P be an arc of an equilatoral hyperbola, O A and O B the equal semi-axes. The radius O P is derived from the semi-axis O A by a hyperbolic versor which has a magnitude x and an axis through O perpendicular to the plane. Now x is not the ratio of the arc A P to either the radius vector O P or the semi-axis O A; but the ratio of twice the area of the sector A O P to the square on O A. In the circle, Fig. 1, the ratio of twice the area of the sector A O P to the square on O A is equal to that of the arc A P to the semi-axis O A; the symbol x may denote either. But in the hyperbolic counterpart it is the ratio of the areas which must be taken. If x denotes the ratio of twice the area of the hyperbolic sector A O P to the square on O A, then as a

matter of truth, not mere definition, cosh x, by which is meant the ratio of O M to O A, is equal to

$$1 + \frac{x^2}{2!} + \frac{x^4}{4!} + ;$$

and sinh x, by which is meant the ratio of M P to O A, is equal to

$$x + \frac{x^3}{3!} + \frac{x^5}{5!} + \quad .$$

We observe that O M and O A have the same direction, while M P is at right angles to O A; hence we conclude that the second series is really at right angles to the first. But instead if $\cos^2 x + \sin^2 x = 1$, we have $\cosh^2 x - \sinh^2 x = 1$; the fact that it is the difference not the sum of the squares which is equal to 1 attaches a scalar $\sqrt{-1}$ before the sinh series. We conclude that the proper expression for the hyperbolic versor is

$$\cosh x + \sqrt{-1} \sinh x \overset{\text{II}}{\beta^{\beta}};$$

and that the exponential expression is $e^{\sqrt{-1}\, x \overset{\text{II}}{\beta^{\beta}}}$. For brevity we will donate $\overset{\text{II}}{\beta^{\beta}}$ by i. Thus $e^{i x}$ denotes a circular angle, and $e^{\sqrt{-1}\, i x}$ a hyperbolic angle.

The process by which equation (4) is usually reduced to equation (6) is highly obscure to the student. We shall state it in a form, such that it will apply to the analogous hyperbolic case. For brevity let n denote the square root of the difference of a^2 and b; in the hyperbolic case n is less than a. Equation (4) may then be written

$$q = e^{-at}\left(c_1 e^{int} + c_2 e^{-int}\right).$$

The arbitrary constants c_1 and c_2 are circular complex quantities; they are not perfectly arbitrary, but are connected in such a way that they involve only two independent quantities. Their magnitudes are equal and their angles supplementary. Hence we can write:

$$c_1 = c(\cos\varphi + i \sin\varphi),$$
$$c_2 = c(-\cos\varphi + i \sin\varphi);$$

then:

$$q = 2c e^{-at}\left(\cos\varphi \frac{e^{int} - e^{-int}}{2} + i \sin\varphi \frac{e^{int} + e^{-int}}{2}\right)$$
$$= i\, 2c e^{-at}\left(\cos\varphi \sin nt + \sin\varphi \cos nt\right)$$
$$= i\, 2c e^{-at} \sin(nt + \varphi).$$

The i is dropped, $2c$ is written A, and thus equation (6) is obtained.

The assumptions usually made in reducing are

$$c_2 = c(\cos\varphi + i\sin\varphi) \text{ and } c_2 = c(\cos\varphi - i\sin\varphi)$$

which is equivalent to making the angles conjugate. The solution then is

$$q = 2ce^{-at}\cos(nt + \varphi)$$

which is the horizontal instead of the vertical projection. The analogous investigation shows that the former is the correct assumption for the initial conditions of the discharge.

In the case of the hyperbolic roots

$$q = e^{-at}\left(c_1 e^{\sqrt{-1}\,int} + c_2 e^{-\sqrt{-1}\,int}\right).$$

Let

$$c_1 = c(\cosh\varphi + \sqrt{-1}\,i\sinh\varphi),$$

and

$$c_2 = c(-\cosh\varphi + \sqrt{-1}\,i\sinh\varphi);$$

then

$$q = \sqrt{-1}\,ice^{-at}\left(\cosh\varphi\,\frac{e^{\sqrt{-1}\,int} - e^{-\sqrt{-1}\,int}}{2} + \sinh\varphi\,\frac{e^{\sqrt{-1}\,int} + e^{-\sqrt{-1}\,int}}{2}\right)$$

$$= \sqrt{-1}\,i\,2ce^{-at}\sinh(nt + \varphi),$$

and by dropping $\sqrt{-1}\,i$ and writing A for $2c$,

$$q = Ae^{-at}\sinh(nt + \varphi).$$

Were conjugate hyperbolic angles taken for the arbitrary constants, the horizontal projection would be obtained, involving $\cosh(nt + \varphi)$ in which case the initial current could not be zero. Either projection satisfies the differential equation, but it is only the former which satisfies the initial condition that there is no current at the beginning.

The meaning of these solutions is illustrated by Figs. 3 and 4.

Fig. 3 represents the circular case. O P multiplied by c represents c_1, and O P^1 multiplied by c represents c_2; O Q multiplied by ce^{-at} represents the first circular solution and O Q^1 multiplied by the same quantity represents the supplementary circular solution. The multiples of O Q and O Q^1 are compounded, their

resultant being $2\,c\,e^{-at}$ of O M which represents sin $(nt + \varphi)$.

In the hyperbolic case (Fig. 4), O P multiplied by c represents c_1, and O P^1 multiplied by c represents c_2; O Q multiplied by $c\,e^{-at}$ represents the first hyperbolic solution, and O Q^1 multiplied by the same ratio represents the supplementary hyperbolic solution. The multiples of O Q and O Q^1 are compounded, their resultant being $2\,c\,e^{-at}$ of O M, which represents the sine of the hyperbolic angle $n\,t + \varphi$.

By differentiation we deduce the solution for the current; let it be denoted by I. As $I = \frac{d\,q}{d\,t}$

$$I = -A\,e^{-at}\,[a \sinh (nt + \varphi) - n \cosh (nt + \varphi)]$$

$$= -A\,\sqrt{a^2 - n^2}\,e^{-at}\left[\frac{a}{\sqrt{a^2 - n^2}} \sinh (nt + \varphi) - \frac{n}{\sqrt{a^2 - n^2}} \cosh (nt + \varphi)\right]$$

$$= -A\,\sqrt{a^2 - n^2}\,e^{-at} \sinh \left(nt + \varphi - \tanh^{-1}\frac{n}{a}\right).$$

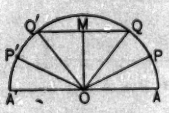


FIG. 3.

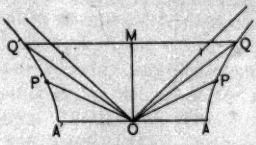


FIG. 4.

Thus the charge is in advance of the current by the hyperbolic angle whose tangent is $\frac{n}{a}$, which is the hyperbolic angle at which both q and I have their maximum value. The same proposition applies, *mutatis mutandis*, to the oscillating discharge.

Writers on this subject call $\frac{1}{a}$ the time constant for an exponential discharge, and $\frac{1}{-a + \sqrt{a^2 - b}}$ and $\frac{1}{-a - \sqrt{a^2 - b}}$ the time constants for the non-oscillating discharge. But from the above presentation of the subject it is evident that $\sqrt{a^2 - b}$ is the analogue of $\sqrt{b - a^2}$ in the circular case. There it means the angular velocity of the auxiliary circular motion; so here it

means the angular velocity of the auxiliary equilateral-hyperbolic motion. In the oscillating case $\frac{2\pi}{\sqrt{b-a^2}}$ gives the period; in the non-oscillating case $\frac{2\pi}{\sqrt{a^2-b}}$ gives the hyperbolic period. By the hyperbolic period is meant the time occupied by the radius-vector of the equilateral hyperbola of unit semi-axis to sweep out twice the area of the circle of unit radius. This definition of *period* applies to the circular case also.

The function $A \sin(nt+\varphi)$ represents the vertical projection of a uniform circular motion of amplitude A, angular velocity n, and epoch φ. Similarly the function $A e^{-at} \sin(nt+\varphi)$ represents (Fig. 5) the vertical projection of the circular spiral motion of the point P having angular velocity n, epoch φ and logarithnically decreasing amplitude $A e^{-at}$. In the same manner the

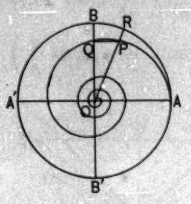


FIG. 5.

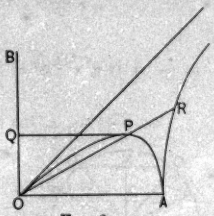


FIG. 6.

function $A e^{-at} \sinh(nt+\varphi)$ represents (Fig. 6,) the vertical projection of the hyperbolic spiral motion of the point P having hyperbolic angular velocity n, epoch the hyperbolic angle φ, and amplitude $A e^{-at}$. It will be observed that this spiral is convergent, for n is less than a.

By putting in the conditions that $I = 0$ and $q = Q$ when $t = 0$, we obtain

$$\varphi = \tanh^{-1}\frac{n}{a}, \text{ and } A = Q\frac{\sqrt{a^2-n^2}}{n}$$

consequently

$$q = Q\frac{\sqrt{a^2-n^2}}{n} e^{-at} \sinh\left(nt + \tanh^{-1}\frac{n}{a}\right)$$

and

$$I = -Q\frac{a^2-n^2}{n} e^{-at} \sinh nt.$$

These curves have a maximum value when the angle is $\tanh^{-1}\frac{n}{a}$; hence when $t = o$ and $t = \frac{1}{n}\tanh^{-1}\frac{n}{a}$ respectively. They have a point of contrary flexure, when the angle is $2\tanh^{-1}\frac{n}{a}$; hence when $t = \frac{1}{n}\tanh^{-1}\frac{n}{a}$ and $t = \frac{n}{2}\tanh^{-1}\frac{n}{a}$ respectively. The properties of either curve are given by the general equation

$$\frac{d^m q}{dt^m} = (-1)^m Q \frac{\sqrt{(a^2 - n^2)}^{m+1}}{n} e^{-at} \sinh\left[nt - (m-1)\tanh^{-1}\frac{n}{a}\right]$$

corresponding to

$$\frac{d^m q}{dt^m} = (-1)^m Q \frac{\sqrt{(a^2 + n^2)}^{m+1}}{n} e^{-at} \sin\left[nt - (m-1)\tan^{-1}\frac{n}{a}\right]$$

in the oscillating case.

The nature of the curves for the charge and the current in the non-oscillating case has not been plain to some electricians of high authority. In the first volume of his work, "Alternating Current Transformer," page 379, Professor Fleming represents the current graphically by an exponential curve, which is far from representing the current correctly. In the first volume of his "Lecons sur l'Electricité," page 256, Professor Gerard represents the charge by an exponential curve which has no maximum at the beginning; and the same representation is given by Professors Jackson in appendix C of their "Alternating Currents." The curves are correctly represented graphically by Doctors Bedell and Crehore in their "Alternating Currents," and by Professor Webster in his "Theory of Electricity and Magnetism."

We deduce the solution for the transition case by means of the principle that in form it must agree with what is common to the two general solutions. Now for the hyperbolic case

$$q = A e^{-at}\left[nt + \varphi + \frac{(nt+\varphi)^3}{3!} + \right],$$

and for the circular case

$$q = A e^{-at}\left[nt + \varphi - \frac{(nt+\varphi)^3}{3!} + \right];$$

hence for the transition case

$$q = A\, e^{-at}\,(\varphi + nt).$$

As $A\,\varphi$ is represented by a length, and $A\,n$ by a linear velocity, let them be denoted by the constants $2\,c$ and $2\,v$. Then $q = 2\,e^{-at}\,(c + vt)$.

In the case of the horizontal projections the only common part is the first term of the series, namely 1; hence b denoting an arbitrary length, we have $2\,e^{-at}\,b$ for that projection. Hence the primary form of the solution of the differential equation in the transition case is

$$q = e^{-at}\,\{[\,b + i\,(c + vt)\,] + [-b + i\,(c + vt)\,]\,\}.$$

This is represented in Fig. 7, which is the transition between Figs. 3 and 4. O P represents $b + i\,c$, and O P^1 represents $-b + i\,c$; O Q represents $b + i\,(c + vt)$ and O Q^1 represents $-b + i\,(c + vt)$; O M represents half of the resultant of O Q and O Q^1.

By putting in the conditions that $I = 0$ and $q = Q$ when $t = 0$, we obtain

$$q = Q\, e^{-at}\,(a\,t + 1)$$

$$\text{and } I = -\,Q\, e^{-at}\, a^2\, t.$$

The general differential co-efficient is

$$\frac{d^m q}{d\,t^m} = (-1)^m\, Q\, e^{-at}\, a^m \left[a\,t - (m - 1)\right].$$

Hence q is a maximum when $t = o$, and has a point of contrary flexure when $t = \frac{1}{a}$; and I has a maximum when $t = \frac{1}{a}$ and a point of contrary flexure when $t = \frac{2}{a}$. Thus we see that 1 takes the place of $\tan^{-1}\frac{n}{a}$ or $\tanh^{-1}\frac{n}{a}$, and that a takes the place of n.

Fig. 8 is the transition between Figs. 5 and 6. The point R describes a uniform motion along the straight line; O P is O R diminished at a uniform geometrical rate, O Q is the vertical projection of O P. The path of P is perpendicular to O A at the point O, whereas in the hyperbolic case it makes an angle of 45°.

If attention is restricted to real roots, it is difficult to see why the transition solution is not of the form $q = A\, e^{-at}$, nor is the matter made very clear in treatises on Differential Equations.

The preceding investigation throws new light on the theory of the quadratic equation. The current theory may be stated as follows: A quadratic equation has either two real roots, or two imaginary roots, the separating case being when the roots are equal. According to the results of the preceding investigation, the theory should be stated as follows: So far as real roots are concerned, a quadratic equation has either two such roots, or else none, the separating case being where they are equal. The two general cases are the real and the impossible. As regards complex roots, a quadratic equation has either two conjugate hyperbolic roots, or else, two conjugate circular roots, the separating case being where they are straight-line. Consider the quadratic equation $x^2 + 2ax + b = 0$. If a^2 is greater than b, the roots are hyperbolic, and

$$x_1 = -a + \sqrt{-1}\, i \sqrt{a^2 - b}$$

$$x_2 = -a - \sqrt{-1}\, i \sqrt{a^2 - b}$$

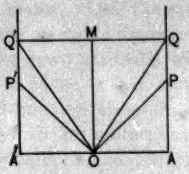


FIG. 7.

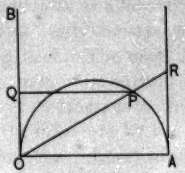


FIG. 8.

If we substitute either root in the equation, we shall find, just as in the case of the circular roots, that the terms which do not involve i cancel one another, and likewise the terms which do involve i. The equation is doubly satisfied by the independent vanishing of the two parts.

The preceding investigation has an important bearing on the theory of the complex quantity, a theory which lies at the foundation of algebraic analysis. The eminent mathematician Cayley maintained that the complex quantity $a + ib$ is the most general magnitude considered by algebra, and that were it fully investigated the science would become *totus teres atque rotundus*. The current doctrine among mathematicians is thus stated in a recent able work on alternating currents, where from the nature of the subject the circular complex quantity is a fundamental idea:

"Within the range of algebra no further extension of the system of numbers is necessary or possible, and the most general number is $a + ib$, where a and b can be integers or fractions, positive or negative, rational or irrational." [1]Let the question be limited to the algebra of the plane although that is in truth an arbitrary restriction, for spherical trigonometrical analysis is as much algebra as is plane trigonometrical analysis. The preceding investigation shows that the ordinary complex quantity is only one-half of the whole subject of plane algebra; for parallel with the circular complex quantity we have a hyperbolic complex quantity, and for every theorem about the former there is an analogous theorem about the latter. If the one is within the domain of algebra, so is the other. Here we have another instance of the danger involved in predicating *impossible*.

1. Steinmetz, "Alternating Current Phenomena," p. 405.

A paper to be presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th–28th, 1887.

[ADVANCE COPY—SUBJECT TO REVISION.]

THE ALTERNATING CURRENT INDUCTION MOTOR.

BY CHARLES PROTEUS STEINMETZ.

Polyphase Induction Motor.

§ 1. *Load Curves.*—In its general behaviour the alternating current induction motor is analogous to the continuous current shunt motor. Like the shunt motor it operates at approximately constant magnetic density. It will run at fairly constant speed, slowing down gradually with increasing load. The main difference, however, is that in the induction motor the current is not passed into the armature by a system of brushes, as in the continuous current motor, but induced in the armature by the alternating field, and in consequence thereof, the primary circuit of the induction motor fulfils the double function of an exciting circuit corresponding to the field circuit of the continuous current shunt motor, and an inducing circuit producing the current in the armature by electro-magnetic induction.

In its electro-magnetic features, however, the induction motor is essentially a transformer. That is, it consists of a magnetic circuit interlinked with two electric circuits, the primary or inducing, and the secondary or induced circuit. The difference between transformer and induction motor is that in the former the secondary is fixed regarding the primary, and the electrical energy induced in the secondary is made use of, while in the latter the secondary is moveable regarding the primary and the mechanical force acting between primary and secondary is used.

The secondary or armature of the motor consists of two or more circuits displaced in phase from each other so as to offer a closed secondary to the primary circuits, irrespective of the relative motion. The primary consists of one or several circuits.

In consequence of the relative motion of the primary and secondary, the magnetic circuit of the induction motor must be arranged so that the secondary while revolving does not leave the magnetic field of force. That means the magnetic field of force must be of constant intensity in all directions, or in other words the component of magnetic flux in any direction in space be of the same or approximately the same intensity but differing in phase. Such a magnetic field can either be considered as superposition of two magnetic fields of equal intensity in quadrature in time and space, or it can be represented theoretically by a revolving magnetic flux of constant intensity, or simply treated as alternating magnetic flux of the same intensity in every direction.

In the polyphase motor this magnetic field is produced by a number of electric circuits displaced from each other in position in space, and excited by currents having the same displacement in phase as the exciting coils have in space.

In the monocyclic motor the one of the two superimposed quadrature fields is excited by the primary energy circuit, the other by the magnetizing or teaser circuit.

In the single phase motor the one of the two superimposed magnetic quadrature fields is excited by the primary electric circuit, the other by the induced secondary or armature currents carried into quadrature position by the rotation of the secondary.

In either case at or near synchronism the magnetic fields are identical.

The transformer feature being predominant, in theoretical investigations of induction motors it is generally preferable to start therefrom.

The characteristics of the transformer are independent of the ratio of transformation, other things being equal. That is, doubling the number of turns for instance, and at the same time reducing their cross-section to one-half, leaves the efficiency, regulation, etc., of the transformer unchanged. In the same way in the induction motor it is unessential what the ratio of primary and secondary is, or in other words the secondary circuit can be wound for any suitable number of turns, provided the same total copper cross-section is used. In consequence hereof the secondary circuit is mostly wound with one or two bars per slot, to get maximum amount of copper, that is minimum resistance of secondary.

The general characteristics of the induction motor being independent of the ratio of turns, it is for theoretical considerations simpler to assume the secondary motor circuit reduced to the same number of turns as the primary, or the ratio of transformation 1, by multiplying all secondary currents and dividing all secondary electromotive forces with the ratio of turns, multiplying all secondary impedances and dividing all secondary admittances by the square of the ratio of the turns, etc.

Thus in the following under secondary current, E. M. F. impedance, etc., shall always be understood their values reduced to the primary, or corresponding to a ratio of turns 1 to 1, although in practice a ratio 1 to 1 will hardly ever be used, as not fulfilling the condition of uniform magnetic reluctance desirable in the starting of the induction motor.

Let in the polyphase induction motor

$Y_0 = g + j\,b$ = primary admittance, or admittance of the primary circuit at open secondary circuit.

$Z_0 = r_0 - j\,x_0$ = primary impedance.

$Z_1 = r_1 - j\,x_1$ = secondary impedance enduced to the primary by the ratio of turns.[1]

All these quantities refer to one primary circuit and one corresponding secondary circuit. Thus in a three-phase induction motor the total power, etc., is three times that of one circuit, in the quarter-phase motor with three-phase armature the impedance of $1\frac{1}{2}$ of the three secondary circuits is to be considered as corresponding to each of the two primary circuits, etc.

Let

e = primary counter electromotive force, or electromotive force induced in the primary circuit by the flux interlinked with primary and secondary (mutual induction).

s = slip, with the primary frequency as unit, that is, $s = 0$ denoting synchronous rotation, $s = 1$ standstill of the motor.

It is then:

$1 - s$ = speed of the motor secondary as fraction of synchronous speed.

$s\,N$ = frequency of secondary currents, where

N = frequency impressed upon the primary

hence

$s\,e$ = E. M. F. induced in the secondary.

1. The self inductive reactance refers to that flux which surrounds one of the electric circuits only without being interlinked with the other circuits.

The actual impedance of the secondary circuit at the frequency $s\,N$ is

$$Z_1' = r_1 - j\,s\,x_1$$

hence,

Secondary current:

$$I_1 = \frac{s\,e}{Z_1'} = \frac{s\,e}{r_1 - j\,s\,x_1} = e\left(\frac{s\,r_1}{r_1^2 + s^2 x_1^2} + j\,\frac{s^2 x_1^2}{r_1^2 + s^2 x_1^2}\right) = e\,(a_1 + j\,a_2)$$

where:

$$a_1 = \frac{s\,r_1}{r_1^2 + s^2 x_1^2} \qquad a_2 = \frac{s^2 x_1^2}{r_1^2 + s^2 x_1^2}.$$

Primary exciting current:

$$I_{oo} = e\;Y_o = e\,[g + j\,b]$$

hence,

Total primary current:

$$I_o = e\,[(a_1 + g) + j\,(a_2 + b)\,] = e\,(b_1 + j\,b_2)$$

where:

$$b_1 = a_1 + g \qquad b_2 = a_2 + b.$$

The E. M. F. consumed in the primary circuit by the impedance Z_o is $I_o\,Z_o$, the counter E. M. F. is e, hence:

Primary terminal voltage:

$$E_o = e + I_o\,Z_o = e\,[1 + (b_1 + j\,b_2)\,(r_o - j\,s_o)\,] = e\,(c_1 + j\,c_2),$$

where:

$$c_1 = 1 + r_o\,b_1 + s_o\,b_2 \qquad c_2 = r_o\,b_2 - s_o\,b_1.$$

Eliminating complex quantities, it is:

$$E_o = e\sqrt{c_1^2 + c_2^2};$$

hence,

Counter E. M. F. of motor:

$$e = \frac{E_o}{\sqrt{c_1^2 + c_2^2}},$$

where:

E_o = impressed E. M. F., numerical value.

Substituting this value in the equations of I_o, I_{oo}, I_o, etc., gives the complex expressions of currents and E. M. F.'s, and, eliminating the imaginary quantities, it is:

Secondary current:

$$I_1 = e\sqrt{a_1^2 + a_2^2}.$$

Exciting current:

$$I_{oo} = e\sqrt{g^2 + b^2}.$$

Primary current:

$$I_o = e\sqrt{b_1^2 + b_2^2}.$$

Denoting by:

$$[M\ N] = [(m_1 + j\ m_2)\ (n_1 + j\ n_2)]$$ the product:

$$m_1\ n_1 + m_2\ n_2,$$ it is:

Torque:

$$T = [I_1\ e] = e^2\ a_1;$$

hence,

Power output:

$$P = (1 - s)\ T = e^2\ a_1\ (1 - s).$$

Primary input:

$$P_0 = [I_0\ E_0] = e^2\ (b_1\ e_1 + b_2\ e_2).$$

Voltamperes, or apparent input:

$$Q = I_0\ E_0.$$

The torque is by this equation given in watts at synchronism, that is $T =$ power which would be developed if the motor would run with this torque at synchronism. This makes us independent of the number of poles, frequency, speed, etc., and thus allows the direct comparison of motors.

The output P includes friction, windage, etc., thus the net mechanical output is P — friction, etc. Since however, friction, etc., depend upon the mechanical construction of the individual motor and its use, it cannot be included in a general formula. P is thus the mechanical output and T the torque developed at the armature conductors.

The efficiency is, $\frac{P}{P_0}$,

the power factor, $\frac{P_0}{Q}$,

the apparent efficiency, $\frac{P}{Q}$,

the torque efficiency, $\frac{T}{P_0}$,

the apparent torque efficiency, $\frac{T}{Q}$,

The meaning of these quantities is the following:

The "efficiency" or "power efficiency" is the ratio of the true mechanical output of the motor to the output which it would give at the same power input if there were no internal losses in the motor.

The "apparent efficiency" or "apparent power efficiency" is the ratio of the mechanical output of the motor to the output which

it would give at the same volt-ampere input if there were neither internal losses nor phase displacement in the motor.

The "torque efficiency" is the ratio of the torque of the motor to the torque which it would give at the same power input if there were no internal losses in the motor.

The "apparent torque efficiency" is the ratio of the torque of the motor to the torque which it would give at the same volt-ampere input if there were neither internal losses nor phase displacement in the motor.

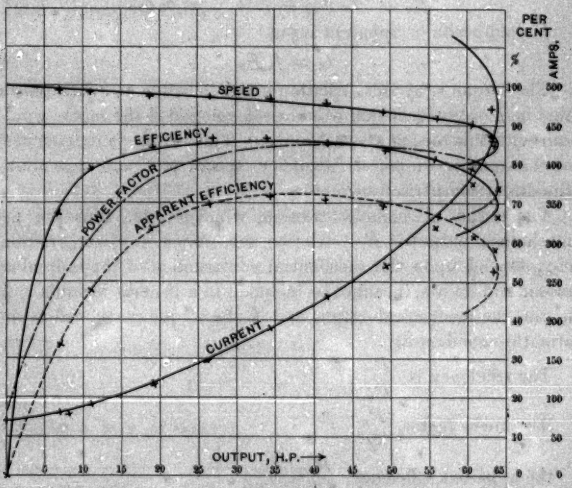


FIG. 1.

1-8-30-900-110, Form "A." 60 Cycles, 8 Poles, 110 Volts. Three Phase. Curves calculated with: $Y = .048 + .384\,j$; $Z_0 = .045 - .124\,j$; $Z_1 = .041 - .124\,j$. Friction: 510 Watts at Synchronism. Observed by Test: ×.

The torque efficiencies are of special interest in starting where the power efficiencies are necessarily zero, but it nevertheless is of importance to find how much torque per watt or per volt-ampere input is given by the motor. These terms are preferable to the terms "torque per watt" or "torque per volt-ampere" generally used in this case, since they are independent of the number of poles, frequency, etc., of the individual motor.

Thus from the quantities: primary admittance, primary im-

pedance and secondary impedance, the induction motor can be calculated.

The predetermination of admittance and impedance belongs in the field of induction motor design and therefore falls outside of the scope of this paper.

As instance, in Figs. 1 and 2 are calculated the load and speed curves of a 60-cycle three-phase eight-polar motor, 110 volts impressed, of the constants.

$Y_0 = .045 + .384j$.

$Z_0 = .045 - .124j$.

$Z_1 = .041 - .124j$ per circuit in delta connection.

510 volts are allowed as friction at synchronism.

The output and torque are three times the values derived directly from calculation since the motor contains three circuits, and the current shown in the diagrams is the current per line, or $\sqrt{3}\times$ the current derived from calculation.

In Fig. 1 are shown in drawn lines the speed, efficiency, and current input of the motor with the H. P. output as abscissae, in dotted lines the apparent efficiency, and in dash dotted lines the power factor.

In Fig. 2 are shown with the speed or the slips in per cent. of synchronism as abscissae, the torque as ordinates for the three-phase armature resistances:

$r_1 = .041$, or short-circuited armature.

$r_1 = .33$.

$r_1 = .76$.

This motor is the *I*-8-30-900-110, Form A, of General Electric Co's make, and the results of test of this motor are marked in Figs. 1 and 2 by crosses, showing the exceedingly close agreement between the calculated values and the results of test.

Examining the equations in the preceding, we see that the expression of the current, counter E. M. F., etc., contains the impressed E. M. F. E_0 as factor, the torque, power output and power and volt-ampere input contain E_0^2 as factor, while the efficiency, power factor, apparent efficiency and torque efficiencies are independent of E_0.

That is, in an induction motor, the efficiency, power factor, apparent efficiency, torque efficiency, apparent torque efficiency at a given slip or speed, and thus starting torque per volt-ampere or watt input are independent of the impressed E. M. F.

The current and counter E. M. F.'s are proportional to the impressed E. M. F.'s.

The torque, power and volt-amperes are proportional to the square of the impressed E. M. F.

This obviously applies only as long as the iron is below saturation, which, however, is always the case.

Under torque, output, etc., are understood the values at the armature conductors disregarding friction. Since the friction is the same at different impressed E. M. F.'s, and the total output varies with the square of the impressed E. M. F., the difference, or

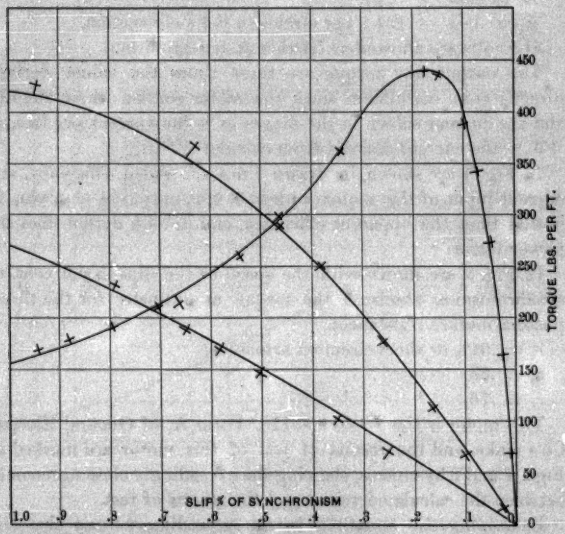


FIG. 2.
1.8–80–900–110, Form "A." 60 Cycles, 8 Poles, 110 Volts. Three Phase. Curves calculated with: $Y = .045 + .384\,j$; $Z_0 = .045 - .124\,j$; $Z_1 = .041 - .124\,j$. Friction: 510 Watts at Synchronism. Observed by Text: ×.

the net mechanical output will be somewhat more than proportional to the square of the impressed E. M. F. On the other hand, at high impressed E. M. F.'s, that is greater output, the motor gets hotter, and thus its electric resistance rises and thereby reduces the output somewhat when running continuously.

Rating the induction motor at a given percentage, say $\frac{3}{4}$ of

maximum output or of maximum torque, the characteristic features of the motor are seen to be entirely independent of the impressed E. M. F. and merely dependent upon the admittance $Y_0 = g + j\,b$ and the impedances $Z_0 = r_0 - jx_0$, $Z_1 = r_1 - jx_1$.

A change of one of the impedances has comparatively little effect on the motor characteristic, provided that the other impedance is changed so that the total impedance $Z_0 + Z_1$ remains the same. Since the primary and the secondary impedance are generally fairly equal, except when intentionally made different, as by inserting high resistance in the secondary to get greater starting torque and greater drop of speed under load, or by inserting reactance in the primary to reduce the starting current and the starting torque, and since from tests of the motor only the sums of the impedances can conveniently be derived, but not the individual impedances, it is mostly sufficient to assume both impedances as equal.

$$Z = Z_0 = Z_1, \quad \text{or:} \quad Z = \tfrac{1}{2}(Z_0 + Z_1).$$

Hereby the induction motor is reduced to two complex imaginary constants Y and Z, or four real constants g, b, r, x, the same terms which characterize the stationary alternating current transformer on non-inductive load.

Instead of conductance g, susceptance b, resistance r, and reactance x, may be chosen as characteristic constants

the absolute admittance $y = \sqrt{g^2 + b^2}$,

the absolute impedance $z = \sqrt{r^2 + x^2}$,

the power factor of admittance $\beta = \frac{g}{y}$,

and the power factor of impedance $\gamma = \frac{r}{z}$.

If the admittance y is reduced n-fold and the impedance z increased n-fold, with the E. M. F. $\sqrt{n}\,E_0$ impressed upon the motor, the speed, torque, power input, and output, volt-ampere input and excitation, power factor, efficiencies, etc., of the motor, that is, all its characteristic features remain the same, as seen from above given equations, and since a change of impressed E. M. F. does not change the characteristics, as seen above, it follows that a change of admittance and of impedance does not change the characteristics of the motor, provided the product $\vartheta = 2\,y \times z$ remains the same.

Thus the induction motor is characterized by three constants only:

The product of admittance and impedance $\vartheta = 2\,yz$, which may be called the characteristic constant of the motor.

The power factor of primary admittance $\beta = \frac{g}{y}$.

The power factor of impedance $\gamma = \frac{r}{z}$.

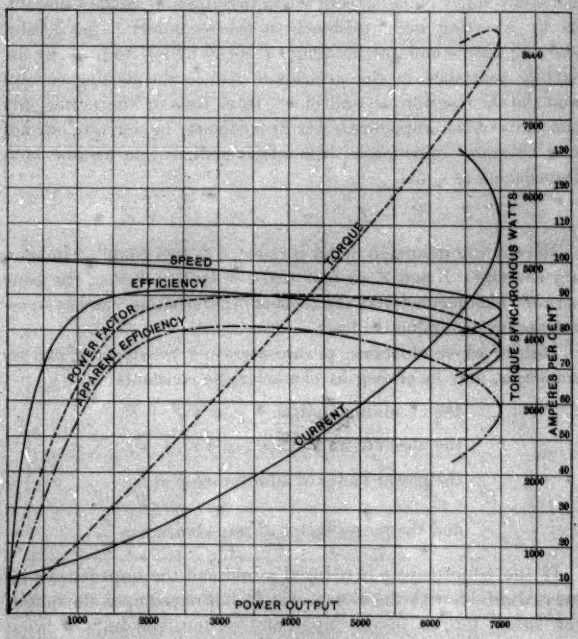


FIG. 3.—Induction Motor. Load Curves. $Z = .1 - .3j$. $Y = .01 + .1j$.

All these three quantities are absolute numbers.

The physical meaning of the latter two, the power factors, is obvious.

The physical meaning of the characteristic constant or the product of admittance and impedance is the following:

If I_{∞} = exciting current,

I_{1o} = current taken by the motor at stand still,

it is approximately

$$y = \frac{I_{\infty}}{E_o},$$

$$z = \frac{E_o}{2\, I_{1o}},$$

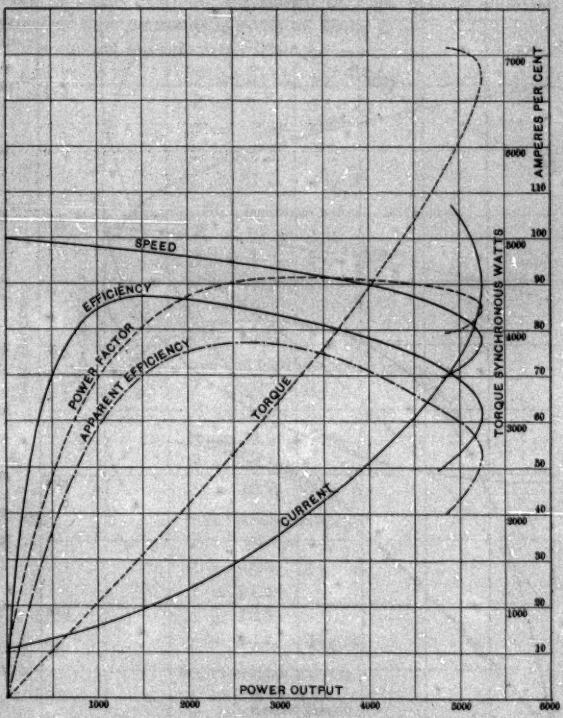


FIG. 4.—Induction Motor. Load Curves. $Z = .2 - .8\,j$. $Y = .01 + .1\,j$.

thus:

$$\vartheta = 2\, yz = \frac{I_{\infty}}{I_{1o}}.$$

The characteristic constant of the induction motor $\vartheta = 2\, yz$ is the ratio of exciting current to short-circuited current.

At given impressed E. M. F, the exciting current I_{oo} is inversely proportional to the mutual inductance of primary and secondary circuit. The short-circuited current I_{1o} is inversely proportional to the sum of the self-inductance of primary and secondary circuit.

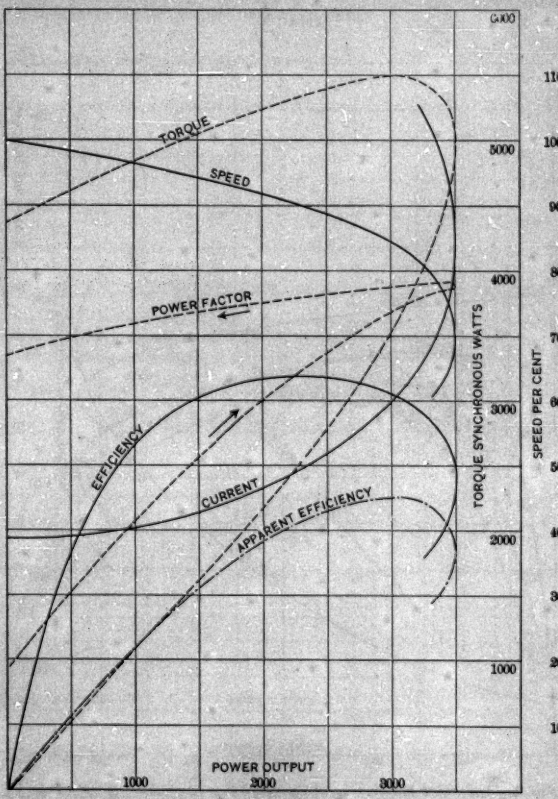


FIG. 5.—Induction Motor. Load Curves. $Z = .3 - .8j$. $Y = .04 + .4j$.

Thus the characteristic constant $\vartheta = 2yz$ is approximately the ratio of total self-inductance to mutual inductance of the motor circuits, that is, the ratio of the flux interlinked with one circuit,

primary or secondary only, to the flux interlinked with both circuits, primary and secondary. The effect of this quantity will be shown in the following in the discussion of individual motors.

To exhibit the effect of the variation of constants on the behavior of the induction motor, a number of characteristic motors have been calculated in the above described manner, and the load curves of some of them are shown in Figs. 3 to 7, while an abstract of their constants is given on Table I.

These motors are calculated with the constants:

1st.— $Y = .01 + .1j$,
$Z = .1 - .3j$, or
$\vartheta = 6.36$,
$\beta = 10.0$,
$\gamma = 31.6$. Fig. 3.

2nd.— High resistance motor.
$Y = .01 + .1j$,
$Z = .2 - .3j$, or
$\vartheta = 7.26$,
$\beta = 10.0$,
$\gamma = 55.4$. Fig. 4.

3rd.— High resistance and high admittance motor.
$Y = .04 + .4j$,
$Z = .3 - .3j$, or
$\vartheta = 34.20$,
$\beta = 10.0$,
$\gamma = 70.7$. Fig. 5.

4th.— High reactance motor.
$Y = .04 + .4j$,
$Z = .05 - .3j$, or
$\vartheta = 24.44$,
$\beta = 10.0$,
$\gamma = 16.4$. Fig. 6.

5th.— High susceptance motor.
$Y = .02 + 4j$,
$Z = .1 - .3j$, or
$\vartheta = 25.35$,
$\beta = 5.0$,
$\gamma = 31.6$. Fig. 7.

Number 1, with load curves shown in Fig. 3, refers to the best motor which can be built at frequencies of 40 to 60 cycles.

TABLE I.

CONSTANTS OF INDUCTION MOTORS.

$E_0 = 110.$

(The motors marked by × are typical motors.)

No. of motor.	No. of diagram.	$Y = g + jb$	$Z = r - jx$	$\vartheta = \frac{2yz}{=y(z_0+z_1)}$	$\beta = \frac{g}{y}$	$\gamma = \frac{\frac{r}{z}}{=\frac{r_0+r_1}{z_0+z_1}}$	T_m = max. torque, synchr. kilowatt.	P_r = rated output, kw. at $\frac{1}{2}$ T_m.	P_m = max. output, in per cent. of P_r.	s = slip, at P_r	Exciting current, per cent. of current at P_r	Power Factor at			Efficiency at			Apparent efficiency at		
												full load.	½ load.	¼ load.	full load.	½ load.	¼ load.	full load.	½ load.	¼ load.
		.005 + .05 j	.1 − .3 j	3.18	10.0	31.6	9.00	5.65	1.33	6.3	8.7	96.6	95	91	85	93	93.5	82.2	88	85
		.01 + .1 j	.05 − .3 j	6.12	10.0	16.4	8.90	5.75	1.42	3.2	16.7	88.7	88.7	77.8	92.4	93.5	90.8	82	83.1	70 5
×1	3	.01 + .1 j	.1 − .3 j	6.36	10.0	31.6	8.25	5.15	1.36	6.3	17.4	89	88.5	74	86.5	91.2	88.2	77.4	81	65
×2	4	.01 + .1 j	.2 − .3 j	7.36	10.0	55.4	7.10	4.90	1.35	11	19.5	91	88.4	71	76	86.5	85	69.2	76	60
		.01 + .1 j	.4 − .3 j	10.04	10.0	80.0	5.30	2.90	1.12	6 18	25.0	93	83	57	66	85	90	61	70	51
		.02 + .2 j	.1 − .3 j	12.70	10.0	31.6	7.90	4.95	1.35	6.3	32	83	74	55	84	87	80	70	64.5	44
		.02 + .2 j	.2 − .3 j	14.52	10.0	55.4	6.80	4.00	1.36	11	36	85	72	50,5	75.5	80.6	74	64.3	58 2	37.5
×4	6	.04 + .4 j	.05 − .3 j	24.44	10.0	16.4	7.90	5.10	1.42	3.2	51 4	69.4	55	37	86.4	83	73.5	60.5	45.5	27
×5	7	.02 + .4 j	.1 − .3 j	25.35	5.0	31.6	7.60	4.75	1.35	6.3	52	71	54	36	82	82.3	75	58.2	44.5	26
		.04 + .4 j	.1 − .3 j	25.40	10.0	31.6	7.30	4.55	1.35	6.3	53.5	71	54	36	79.7	79	69	56	42.5	25
×3	5	.04 + .4 j	.3 − .3 j	34.20	10.0	70.7	5.50	3.10	1.18	16.5	62.5	75	53	37	60.6	61.3	47	45.3	32.5	17
		Single	phase	Motors:																
1_1		.03 + .3 j	.1 − .3 j	12.72	10	31.6	2.9	6.4	1.43	2.8	36	82	73	52.5	84.5	85	78	70	61.5	40.5
			.033 − .1 j																	
2_1		.03 + .3 j	.2 − .3 j	14.52	10	55.4	7.5	4.8	1.36	4.3	44.3	85	67.5	47	74.5	78	69	62	53	33.5
			.067 − .1 j																	
4_1		.12 + 1.2 j	.05 − .3 j	48.88	10	16.4	8.8	5.8	1.43	1.9	73	92	36	24.5	76	68	52	39.5	24.5	13
			.0167 − .1 j																	
5_1		.06 + 1.2 j	1 − .3 j	50.7	5	31.6	7.75	5.0	1.41	3.4	78	58.5	35	24	69.5	62.5	47.5	37	22	11
			.033 − .1 j																	
3_1		.12 + 1.2 j	.3 − .3 j	68.4	10	70.7	4.3	2.67	1.33	6.8	92	60.5	45.7	38.5	40	38.6	17	24.3	13.5	6.8
			.1 − .1 j																	

As seen, the efficiency rises very rapidly at light loads, reaches a maximum of 91%, and then slowly drops to 88% at full load. The power factor rises somewhat slower, but is already 74% at quarter load. The apparent efficiency is very high also, above 80%, and rises at light loads quite rapidly. The exciting current is very small. The drop of speed, 6%, at full load, could be made less by lessening the armature resistance. In very large motors as

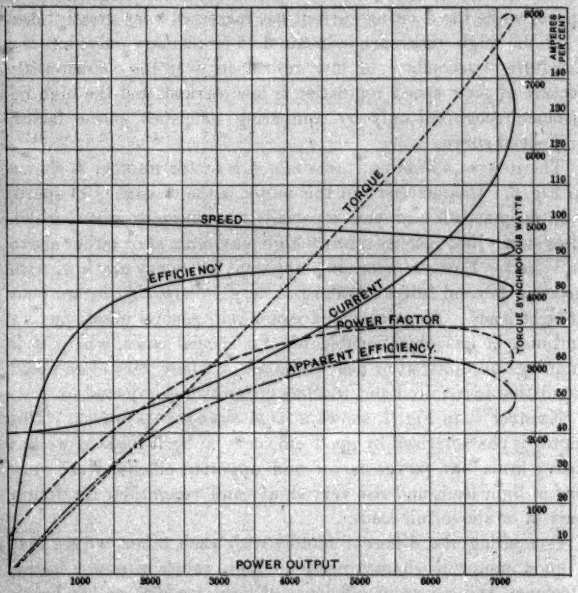


FIG. 6.—Induction Motor. Load Curves. $Z = .05 - .3j$. $Y = .04 + .4j$.

close a speed regulation as 1 to $1\frac{1}{2}$% has been reached. Thus this motor is equally as satisfactory at light loads as at heavy loads.

Number 2 in Fig. 4 shows the typical *high resistance motor*. It is characterized by poor speed regulation, a drop of 11% at full load, an efficiency curve reaching very high values at light load, but falling off with load, while the power factor rises slowly, but reaches very high values at heavy loads. The apparent efficiency is quite fair and the exciting current the same as in the first

motor, thus due to the decreased output of this motor a somewhat higher percentage of full load current, when rating the motor at $\frac{2}{3}$ maximum torque.

If besides high resistance the motor has *high admittance* also, as number 3 in Fig. 5, the high efficiency maximum at light loads is cut off and the efficiency curve flattened and lowered. The power factor rises very slowly at light loads, reaching a lower maximum. Characteristic, however, remains the large drop in speed, while the exciting current has increased very greatly also.

If the high resistance is in the field or primary only, but the armature or secondary of low resistance, even the characteristic feature of poor speed regulation is less marked, and the high resistance recognized only by comparing efficiency, power factor, and speed curve.

The reverse, a *high reactance motor*, is motor number 4, shown in Fig. 6. Characteristic of this motor is the constancy of speed, 3.3% drop at full load, and especially the efficiency curve, which rises slowly, but reaches a fairly high maximum at or rather above full load. Power factor and apparent efficiency are low, with maxima beyond full load, and rise very slowly, that is, are poor at light loads. As seen, such a motor is in general unsatisfactory and may be less objectionable only in special cases, where it is running constantly at or near full load, or where very close speed regulation is required and wattless currents less objected to.

Number 5, in Fig. 7, shows a *high susceptance motor*. This motor is characterized by good efficiency at light loads as well as heavy loads, but power factor and apparent efficiency are very low at light loads and rise very slowly and reach their maximum only at or above full loads.

Comparing the different motors with each other, we see that a good motor is characterized by high values of power factor, efficiency and apparent efficiency at light loads as well as heavy loads, by fairly close speed regulation and low exciting current.

High resistance is characterized by *poor speed regulation* and lowering of the efficiency at heavy loads, *high reactance* by very good speed regulation, good efficiency at heavy loads, and low power factor and apparent efficiency at light loads, *high admittance* by high exciting current and poor power factor and apparent efficiency at light loads.

An abstract of the data of these motors and a number of other motors is given in Table I.

§ 2. Speed Curves.

The load curves discussed in the preceding are especially characteristic of the action of the motor when doing work at its proper speed near synchronism. The action in starting, or in running at intermediate speeds, or beyond synchronism, or when driven backwards, are best shown by what I may call the speed

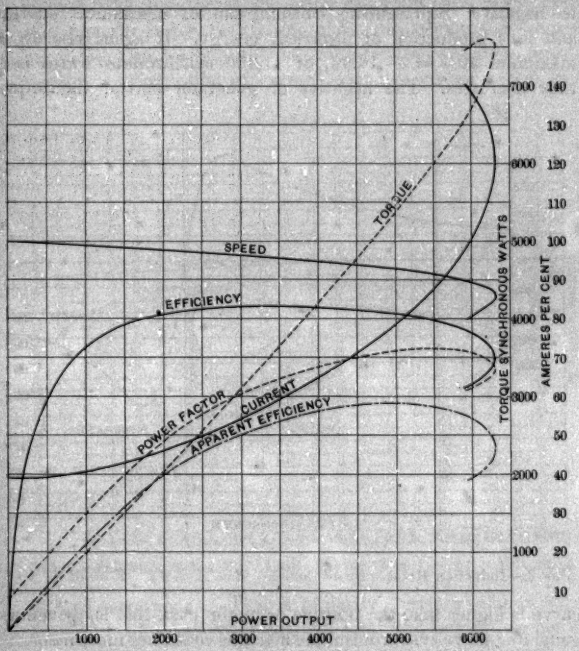


Fig. 7.—Induction Motor. Load Curves. $Z = .1 - .3j$. $Y = .02 + 4j$.

curves of the motor. A set of such curves, corresponding to the motor number 1 in Fig. 3, are shown in Fig. 8, of the constants

$$Y = .01 + .1j, \qquad Z = .1 - 3j.$$

These curves give with the speed, that is, the slip, as abscissae, the torque in watts at synchronism and the current input of the motor. As seen, the torque is zero at synchronism, increases with

increasing slip, that is, decreasing speed, reaches a maximum of 8,250 synchronous watts at 16.5% slip, and then decreases again, reaching 2,920 synchronous watts at $s = 1$, that is, standstill, and keeps on decreasing for $s > 1$, that is, backward rotation, without change of direction, thus representing consumption of energy by the motor. For $s < 0$, that is, above synchronism, the torque curve is the counterpart of the torque curve for $s > 0$, but is negative, representing consumption of mechanical energy and thus production of electrical energy. It again reaches a maximum at $s = -16.5\%$, of 11,400 synchronous watts, and then decreases. The negative or generator part of the torque

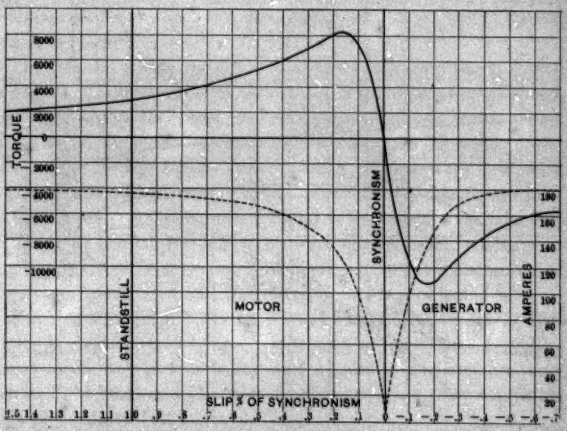


FIG. 8.—Induction Motor. Speed Curves. $Z = .1 - 8j$. $Y = .01 + .1j$.

curve is higher than the positive or motor part, that is, driven as generator above synchronism the machine consumes more mechanical torque than it produces running as motor below synchronism.

Thus the induction motor shares with the continuous current shunt motor the feature to be a motor only below a definite speed, but to become generator or act as brake, by returning energy into the line, when driven above its speed.

The load curve of the motor corresponds to the part of the speed curve between synchronism and maximum torque at positive slip. From the part of the speed curve between synchronism

and maximum torque at negative slip, or above synchronism, a corresponding load curve can be constructed of the machine as induction generator. This curve is shown in Fig. 9. As seen, it is very similar to the motor load curve, except that the speed curve bends upwards.

As generator the induction machine differs from the synchronous alternating current generator, or generator with constantly excited field, in-so-far as the latter can yield current and output at any power factor, that is, any phase displacement corresponding to the load, while in the induction generator at given terminal voltage to every value of current output a certain power factor

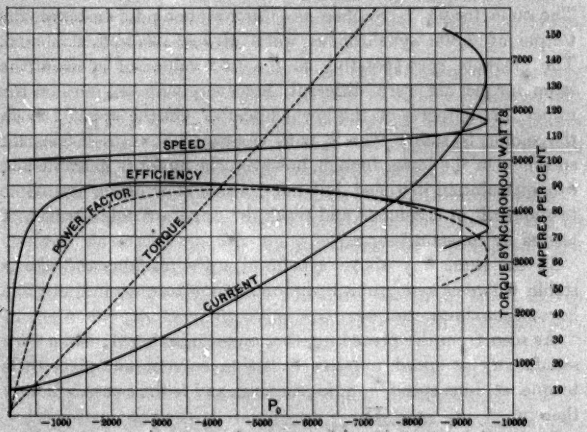


FIG. 9.—Induction Generator. Load Curves. $Z = .1 - .3j$. $Y = .01 + .1j$.

of load corresponds. That is, to derive a certain value of current from the induction generator, the total load put on it must have the particular power factor corresponding to this current, and besides leading current, or if the power factor of the load changes, current and voltage of the induction generator will change accordingly. In consequence thereof, in general the induction generator is stable only, if at least a part of the load consists of synchronous motors.

The current in the induction machine is a minimum at synchronism and decreases on either side of synchronism, first very

rapidly and then slower, and becomes fairly constant afterwards, as seen in Fig. 8. In the particular motor under discussion, the whole variation of current is practically comprised within the range from $s = +.4$ to $s = -.3$, that is, the current at standstill is very large and remains practically constant until about $\frac{3}{4}$ of synchronous speed is reached. Thus such a motor with low armature resistance will require a very large current, not only in starting, but also at intermediate speeds.

Restricting our attention to that part of the torque curve below synchronism, we see that the torque curve consists of two branches, the upper branch from maximum torque to synchronism, and the lower branch from maximum torque to standstill. The same torque is reached on either branch; for instance, the torque of 4,800 synchronous watts at $s = .05$, and at $s = .6$. The currents corresponding to the two values of speed at the same torque are very different, however, 52.5 amperes on the upper, 171 amperes on the lower branch. On the upper branch the motor is stable, that is, with constant load runs at constant speed. On the lower branch, however, the motor is unstable and cannot maintain its speed, but must either slow down and come to standstill, or accelerate and reach the upper or stable branch, if loaded by constant torque.

In the same way above synchronism the machine as brake is stable between synchronism and maximum torque, and unstable beyond maximum torque.

As seen from the preceding, the motor number 1, while very satisfactory at speed, requires excessive current and gives little torque at low speed and in starting, and is thus unsatisfactory therein.

In the discussion of load curves in the preceding, we have seen that high resistance motors have a large drop of speed and thus reach a maximum torque point at lower speeds, that is, are in starting nearer to the maximum torque point, or in other words, have a greater starting torque.

From the equations of the induction motor it is obvious that this greater torque at low speeds is not due to the primary resistance, but exclusively to the secondary or armature resistance.

The armature resistance r_1 enters only in the equation of secondary current:

$$I_1 = \frac{s\,e}{r_1 - j\,s\,x_1} = e\left[\frac{s\,r_1}{r_1^2 + s^2 x_1^2} + j\,\frac{s^2 x_1}{r_1^2 + s^2 x_1^2}\right] = e\,(a_1 + j\,a_2),$$

and in the further equations only indirectly in so far as r_1 is contained in a_1 and a_2.

Increasing the armature resistance n-fold, to $n\,r_1$ we get at an n-fold increased slip $n\,s$:

$$I_1 = \frac{n\,s\,e}{n\,r_1 - j\,n\,s\,x_1} = \frac{s\,e}{r_1 - j\,s\,x_1},$$

that is the same value, and thus the same values for e, I_0, T, P_0, ϑ, while the power is decreased from $P = (1-s)\tau$ to $P = (1-ns)\,T$, and the efficiency and apparent efficiency are correspondingly reduced. The power factor is not changed. Hence,

An increase of armature resistance r_1 produces a proportional increase of slip n, and thereby corresponding decrease of power, efficiency and apparent efficiency, but does not change the torque, current and power factor.

Thus the insertion of resistance in the armature or secondary of the induction motor offers a means to reduce the speed corresponding to a given torque, and thereby any desired torque can be produced at any speed below that corresponding to armature short circuit, without changing torque or current.

Hence, given the speed-torque curve of a short-circuited motor, the torque curve with resistance inserted in the armature can be derived therefrom directly by increasing the slip in proportion to the increased resistance.

This is done in Fig. 10, in which are shown the speed curves of the motor number 1 between standstill and synchronism, for:

Short-circuited armature: $r_1 = .1$.

.15 ohms resistance inserted in armature: $r_1 = .25$.

.5 ohms additional resistance inserted in the armature: $r_1 = .6$.

1.5 ohms additional resistance inserted in the armature: $r_1 = 1.6$.

The corresponding current curves are shown on the same sheet.

As seen, with short-circuited armature the maximum torque of 8,250 synchronous watts is reached at 16.5% slip. The starting torque is 2,950 synchronous watts, and the starting current 176 amperes.

With armature resistance $r_1 = .25$, the same maximum torque is reached at 40% slip, the starting torque is increased to 6,050 synchronous watts, and the starting current decreased to 160 amperes.

With armature resistance $r_1 = .6$, the maximum torque of 8,250 synchronous watts takes place in starting, and the starting current is decreased to 124 amperes.

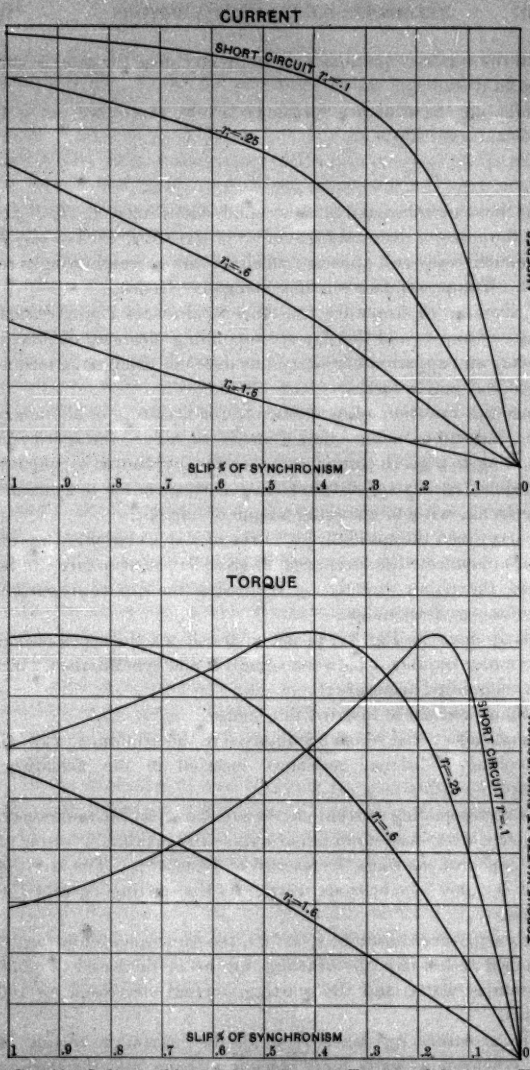


Fig. 10.—Induction Motor. Speed Curves. Torque and Current. $Y = .01 + .1j$. $Z = .1 - .3j$. Arm. Resistance: $r_1 = .1, .25, .6, 1.6$.

With armature resistance $r_1 = 1.6$, the starting torque is below the maximum, 5,620 synchronous watts, and the starting current is only 64 amperes.

In the two latter cases the lower branch of the torque curve has altogether disappeared and the motor speed is stable over the whole range, that is, the motor starts with the maximum torque which it can reach, and with increasing speed torque and current decrease, that is, the motor has the characteristic of the continous current series motor, except that it cannot race, but its maximum speed is limited by synchronism.

On the same diagram, Fig. 10, are shown the currents corresponding to the different values of secondary resistance.

The apparent torque efficiencies of the motor under the four conditions of armature resistance are given in Fig. 11. They show that, although a considerable starting torque can be reached by a moderate armature resistance, of $r_1 = .25$, the apparent torque efficiency or torque per ampere input is still very low under this condition, that is, the motor starts very inefficiently, and, as seen in the preceding discussion of high resistance motors, is rather inefficient at speed. The same diagram also shows the torque efficiencies. It follows herefrom that permanent resistance in the armature of an induction motor can be used to secure good starting torque at the sacrifice of current in starting, and of efficiency and speed regulation when running, but cannot be used to limit the starting current, the latter requiring so large an armature resistance as to make the motor entirely unfit when running.

This brings us to the investigation of the action of the induction motor in starting.

The condition in starting is $s = 1$.

Substituting $s = 1$ in the induction motor equations gives starting torque, current, power factor, etc.

$$I_1 = \frac{e}{r_1 - j\,x_1} = e\left[\frac{r_1}{r_1^2 + x_1^2} + \frac{j\,x_1}{r_1^2 + x_1^2}\right] = e\,(a_1 + j\,a_2)$$

$$a_1 = \frac{r_1}{r_1^2 + x_1^2} \qquad a_2 = \frac{x_1}{r_1^2\,x_1^2},$$

$$I_{oo} = e\,(g + j\,b).$$

$$I_o = I_1 + I_{oo} = e\,[(a_1 + g) + j\,(a_2 + b)] = e\,(b_1 + j\,b_2)$$

$$b_1 = a_1 + g \qquad b_2 = a_2 + b.$$

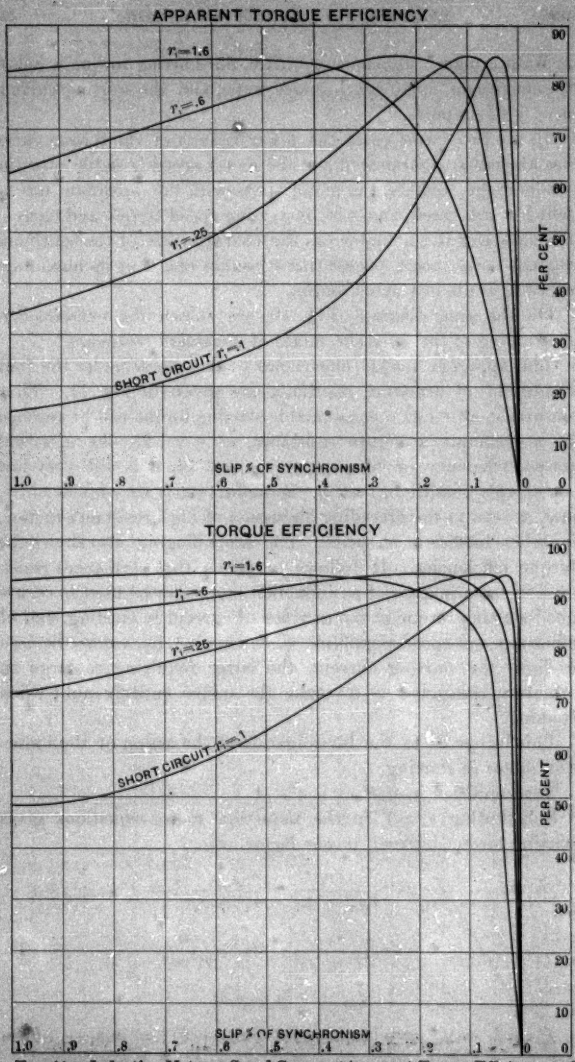


FIG. 11.—Induction Motor. Speed Curves. Apparent Torque Efficiency and Torque Efficiency. $Y = .01 + .1j$. $Z = .1 - .3j$. Armature Resistance. $r_1 = 1.6, .6, .25, .1$.

$$E_0 = e + I_0 Z_0 = e\,[1 + (b_1 + j\,b_2)\,(r_0 - j\,x_0)] = e\,(c_1 + j\,c_2)$$

$$c_1 = 1 + r_0\,b_1 + x_0\,b_2 \qquad c_2 = r_0\,b_2 - x_0\,b_1.$$

$$e = \frac{E_0}{\sqrt{c_1^2 + c_2^2}}.$$

$$I_0 = e\,\sqrt{b_1^2 + b_2^2}.$$

$$T = e^2\,a_1.$$

$$P_0 = [I_0\,E_0] = e^2\,(b_1\,c_1 + b_2\,c_2).$$

$$Q = I_0\,E_0.$$

Power factor $\frac{P_0}{Q}$.

Torque efficiency $\frac{T}{P_0}$.

Apparent torque efficiency $\frac{T}{Q}$.

From these equations are calculated for the motor number 1 of

$$Y = .01 + .1\,j,$$

$$Z = .1 \quad - .3\,j,$$

the starting torque, current, and torque efficiencies at various resistances and reactances in the secondary and in the primary, and plotted in the diagrams, Figs. 12 and 13.

In Fig. 12 is given, with additional armature resistance R as abscissæ, the values of starting torque, starting current, power factor, torque efficiency and apparent torque efficiency.

In Fig. 13 are given the corresponding values, with reactance inserted in the secondary.

The insertion of resistance or reactance in the primary has only the effect of decreasing the voltage at the motor terminals and thereby decreasing the torque in proportion to the square of the voltage at the motor terminals, and the apparent torque efficiency directly proportional to the voltage at the motor terminals, that is, is a very inefficient and unsatisfactory means of starting, and suitable by its simplicity only where no starting torque is required, to limit the starting current. By the use of additional resistance in the armature or secondary in starting, torque can be produced, as seen, with the same current, power factor and torque efficiencies as correspond to the same torque when running.

In Fig. 13, representing the effect of reactance in the secondary

circuit, the torque, current, etc., are shown for positive values or reactive coils, as well as negative values or condensers.

As seen, by the insertion of reactive coils in the secondary of

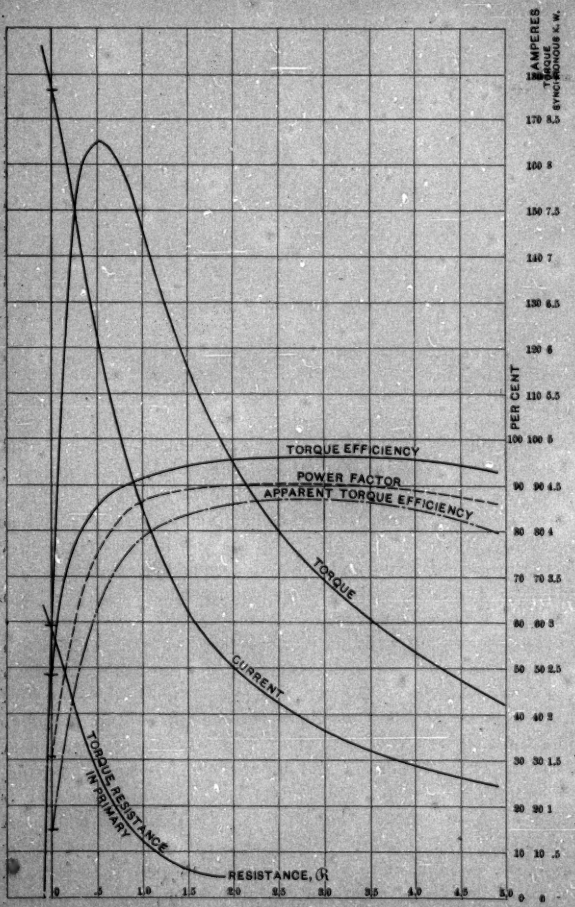


FIG. 12.—Induction Motor. Starting Torque, Turrent, Efficiencies and Power Factor. $Y = .01 + .1j$. $Z = .1 - .8j$. Resistance in Armature.

the induction motor, the torque decreases rapidly, and the effect of secondary inductive reactance is practically identical with that of the insertion of reactance in the primary circuit, that is, the use of inductive reactance in the armature, or the secondary is of no practical value.

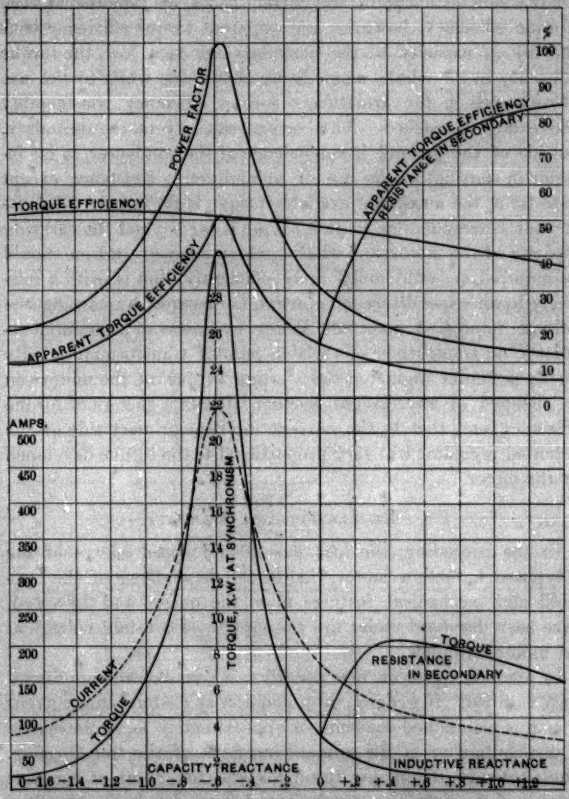


FIG. 13.—Induction Motor. Starting Torque, Current, Efficiencies and Power Factor. $Y = .01 + .1j$. $Z = .1 - .3j$. Reactance in Armature.

By the insertion of negative reactance or capacity, however, torque and current of the motor rise enormously, reaching a

maximum of 30,200 synchronous watts and 530 amperes at — .58 ohms additional capacity reactance, that is, 3.66 times the maximum torque available with armature resistance, at 4.22 times the current corresponding thereto. At this point the power factor is 100%, that is, the current in phase with the impressed E. M. F. On one side of this point the current leads, on the other it lags. Torque efficiency, however, and apparent torque efficiency with the use of capacity in the secondary are very low, the torque efficiency in the whole range being about 50%, while by the use of resistance in the armature a torque efficiency considerably above 90% is reached. That means, capacity in the secondary, outside of the general inconvenience of the condenser, is far inferior in starting, to the use of non-inductive resistance, except in-so-far as the maximum available torque is far larger. But the current corresponding to this torque is far beyond the carrying capacity of the motor, and where such an excessive torque should be required, it could much more efficiently, that is, with a relatively lesser expenditure of current, be secured by varying the voltage impressed upon the motor by means of a potential regulator or transformer of variable ratio of transformation. By such a potential regulator the starting torque of the motor can be changed in any desired manner without a change of torque efficiency, etc., that is, the current input at primary side of the potential regulator will vary proportional to the torque developed by the motor.

§ 3. Regulation and Stability.

In the preceding, the load curves and speed curves of the polyphase induction motor, that is, the dependence of the electrical and mechanical features upon the output and the speed, have been discussed under the assumption of constant voltage at the motor terminals.

In practice, however, this condition is usually only approximately fulfilled. In general, the voltage in any alternating current system is maintained constant, or approximately so, at the centre of distribution or at the primary terminals of the transformers. Thus, between the motor terminals and the point of constant voltage of the system, a certain impedance exists in the circuit.

If now, as it is reasonable to expect, the distribution voltage, ratio of transformation, etc., are chosen so as to bring the rated voltage at full load at the motor terminals, at light load the

voltage at the motor will be high, and thus the exciting current greater than at the rated voltage. Inversely at overload the voltage at the motor terminals will drop below the rated voltage, and thus the maximum torque and the maximum output of the motor be decreased in proportion to the square of the reduced voltage, that is, the more, the greater the impedance of lines, transformers, etc., is.

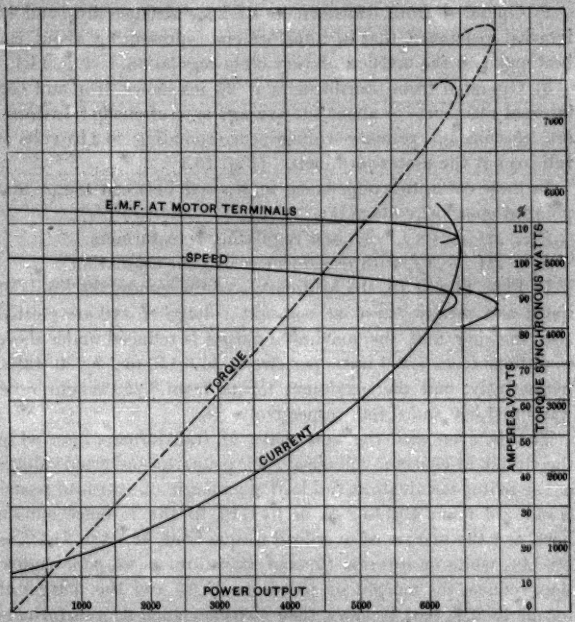


FIG. 14.—Induction Motor. Load Curves. $Y = .01 + .1\,j$. $Z = .1 - .8\,j$. Operated from transformers of impedance, $Z = .04 - .08\,j$, at constant primary potential of 114.1 volts, corresponding to 110 volts at motor terminals at 5000 watts load.

Thus, when operated under these conditions of practice, the induction motor does not give the same margin of overload as when operated at constant impressed voltage.

This at once shows the desirability of designing the induction motor with sufficiently large margin of overload, and the necessity of choosing the supply circuit, and especially the transformers, of as low impedance as possible.

As an instance are shown, in Figs. 14 and 15, the load curves of the motor discussed in the preceding, of the constants:

$$Y_0 = .01 + .1\,j,$$
$$Z = .1 - .3\,j,$$

rated at 5,000 watts per circuit full load, corresponding to 59 amperes at 110 volts impressed, when operated:

1) At constant impressed voltage of 110 volts. (Fig. 3.)

2) Operated from transformers of 2% resistance drop and 4% internal reactance, that is, transformers representing about the best make on the market, of very close regulation. (Fig. 14.)

3) Operated from transformers of 2% resistance drop and 15% internal reactance, or about the average type of cheap transformers, at constant primary voltage corresponding to 110 volts at full load at the motor terminals. (Fig. 15.)

In these cases, the impedance interposed between motor and point of constant voltage is:

$Z = .04 - .08\,j$, with best regulating transformers.

$Z = .04 - .3\,j$, with transformers of poor regulation.

In Figs. 14 and 15, the load curves of the motor, the limits of speed and torque curve at constant voltage of 110 are plotted also, showing that the maximum output is reduced under these conditions from 7,000 watts per circuit to 6,450 and 5,780 watts, respectively, and the maximum torque from 8,250 synchronous watts to 7,500 and 6,460, respectively.

That is, even with the best make of transformers inserted in the circuit, at constant voltage at their primaries and rated voltage at the motor terminals at full load, the margin of over-load power is reduced from 40% to 29%, or by 11% in the instance chosen here, and the margin of over-load torque from 55.5% to 41.5%, or by 14%, while an inferior type of transformers, of poor regulation, reduces the margin of power to 15.6% and the margin of torque to 22%, that is more than twice as much as transformers of close regulation. In consequence thereof, with transformers of poor regulation the motor is at full load already dangerously near the maximum output point, although at constant impressed voltage it has ample margin to carry any reasonable over-load.

Still greater is the decrease of voltage, and thus of torque, in starting, especially with low resistance armature, due to the large currents consumed under these circumstances. With an armature containing a variable resistance of sufficient size, limiting the starting current, the starting torque is less affected by the trans-

former. Thus, with short-circuited armature, in the motor chosen as instance, the starting torque and starting voltage drop from 2,950 synchronous watts at 110 volts to 2,420 synchronous watts at 99.5 volts with good transformers, and only 1,635 synchronous watts at 82 volts with poor transformers, while the starting current is correspondingly decreased from 176 amperes to 139 and 131 amperes, respectively, but the exciting current, or

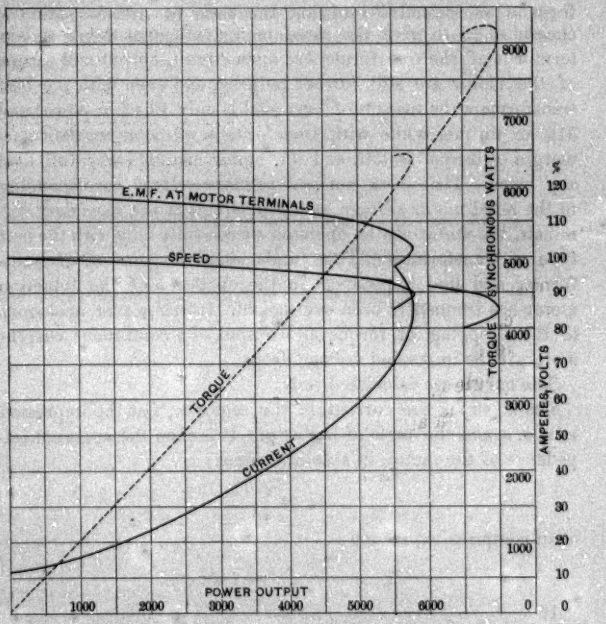


FIG. 15.—Induction Motor. Load Curves. $Y = .01 + .1j$. $Z = .1 - .3j$. Operated from transformers of impedance, $Z = .04 - .3j$, at constant primary potential of 131 volts corresponding to 110 volts at motor terminals at 5000 watts load.

current, when running light, increased from 10.7 to 11 and 11.45 amperes, respectively, due to the increase of voltage at light load.

In consequence thereof, the characteristic constant, which is approximately equal to starting current divided by current at standstill, is increased from 6.1% at constant impressed voltage

to 6.9% with good, and 8.75% with poor transformer, with the result that the motor becomes inferior in every respect in correspondence with the increase of the characteristic constant ϑ, as discussed in the preceding. For instance, the exciting current rises from 17.4% to 20 and 24.7% of the current at $\frac{2}{3}$ maximum torque.

If in the installation of the motor the mistake is made not to allow for the drop of voltage taking place even in the best transformers on inductive load, but the ratio of transformation is chosen so as to give the rated motor voltage at the secondary terminals of the transformers at open circuit, output and torque of the motor are still further reduced, and even with the best transformers the margin of over-load is only 19.4% in power and 31% in torque, while with transformers of poor regulation no margin of torque is left, and the motor cannot carry full load any more. That is, at constant primary voltage corresponding to the rated motor voltage at open circuit at the secondary terminals, the motor can be operated successfully only with the best type of transformers. This fundamental importance of transformer and line impedance on the operation of the induction motor has frequently been overlooked. It is, however, analogous to the dropping of torque and output of a continuous current motor, if the impressed voltage drops.

The curves are calculated thus:

Let at slip s the current in the motor $= i$ at the impressed E. M. F. e, and the angle of lag $= \varphi$. It is then the apparent impedance of the motor, in absolute value:

$$z_m = \frac{e}{i},$$

or in compress expression:

$$Z_m = \frac{e}{i}(\cos\varphi - j\sin\varphi).$$

If

$$Z = r - jx$$

equals the impedance of the transformer, etc., the total impedance of the system of motor, transformer, etc., is:

$$Z^1 = (r + \frac{e}{i}\cos\varphi) - j(x + \frac{e}{i}\sin\varphi),$$

or, absolute:

$$z^1 = \sqrt{(r + \frac{e}{i}\cos\varphi)^2 + (x + \frac{e}{i}\sin\varphi)^2}.$$

At full load, it is:

$$e = e_0, \qquad i = i_0^1,$$

hence:

$$z^1 = Z_0^1 = \sqrt{(r + \frac{e_0}{i_0^1} \cos \varphi_0)^2 + (x + \frac{e_0}{i_0^1} \sin \varphi_0)^2},$$

and:

$$e^1 = i_0^1 z_0^1 = i_0^1 \sqrt{(r + \frac{e_0}{i_0^1} \cos \varphi_0)^2 + (x + \frac{e_0}{i_0^1} \sin \varphi)^2},$$

the constant primary impressed voltage of the system; thus, if at slip s and voltage e_0 the current $i = i_0$, the motor impedance is:

$$z_m = \frac{e_0}{i_0},$$

and the voltage at the motor terminals:

$$e = e_0^1 \frac{z_m}{z_1},$$

and the motor current has to be changed in the proportion:

$$\frac{e}{e_0};$$

the motor output and torque in the proportion:

$$\left(\frac{e}{e_0}\right)^2.$$

A paper to be presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th-28th, 1887.

[ADVANCE COPY.—SUBJECT TO REVISION.]

A NEW FORM OF INDUCTION COIL.

BY ELIHU THOMSON.

The induction coil presently to be described, it is believed constitutes a new type employing the principle of a "substitute primary" or "secondary primary," which principle has been applied by me in a variety of ways.

The prime object of this coil is to permit the direct connection to circuits of considerable potential for obtaining energy for the production of high potential discharges, like those of a Ruhmkorff coil for working Röntgen ray vacuum tubes, and for such like purposes. The object, also, was to avoid the employment of banks of lamps or storage batteries, and to limit the energy consumed to only that amount required to work the coil itself. Furthermore, no larger condensers than those ordinarily used with an induction coil of equal capacity are needed, and no air-blast, while the coil as a whole is still available as an ordinary Ruhmkorff without change in its structure or connections.

To illustrate the principle, reference is made to Fig. 1, where *p n* represent connections to mains at, say, 110 volts difference of potential; 1 1 is an iron wire core around which are wound two coils, one over the other, either of which may, of course, be the primary. The inner coil P in the figure is made the primary, and is wound with many turns of comparatively fine wire. For 110 volts it may have some thousands of turns and be wound with a a wire safe for .5 to .75 ampere. The outside wire, S, may be coarse or fine. In the figure it is quite coarse and of relatively few turns, since it is assumed to give low potential and large current. The coil S is so proportioned as to be practically almost short-circuited at intervals by its load at B, which is three cells of

storage battery in series, for example. The object is assumed to be that the batteries are charged by transference of energy from coil P to S at low potential in S. The coil S should have ample copper so as to lower its internal resistance as much as possible; the resistance of the cells B should be low; and the average voltage of discharge of S much superior to the counter E. M. F. of B. Two synchronously revolving break-pieces, E, F, which may, in fact, be combined into one, are used; E is for governing the intervals of passage of current in coil P and connection of condenser C across the break or interruption periodically made between one terminal of P by a brush G and a metallic segment on E occupying a considerable arc on its periphery. Brush H connects to main *n*. Back of the main segment on E is a small condenser segment in continuous connection with one side or foil of the condenser, and the other side is connected to the other terminal of P, or that

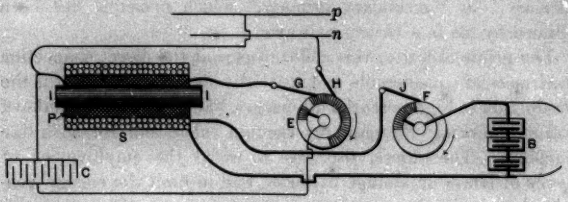


FIG. 1.

leading direct from line *p*. The contact maker and breaker F has a segment which is in continuous connection with one terminal of battery B to be charged, and which touches a stationary brush J, at or about the time of the break between brush G on the main segment of E. The battery B may have terminals by which it may furnish current while being charged.

Now let the break-wheels E and F be given rapid revolution, say, 10, 20 or 30 per second. The contact of brushes G and H with the main segment of E passes current for a certain considerable fraction of the revolution, at full line potential of 110 volts, through primary P. The current rises gradually during this period, and may at the end attain a value of one ampere, more or less. With slow revolution it would be limited by the resistance of P chiefly, but at rapid rates, the time constant of P acting as a self-induction, determines the ultimate value of current

before breaking. Upon the break of brush G with the main segment, it touches the condenser segment which is thereby put across the break, but the circuit of S is also closed by contact of segment on F with brush J. The condenser receives only a small charge on account of the circuit of S having been closed. In fact, the break at G with main segment of E would be nearly sparkless without the condenser C, but what slight self-induction is not wiped out by the mutual induction of the currents in S and P is very easily taken care of.

The magnetizing of the core I I, or absorption of energy is by P, while delivery of energy is by S acting as if nearly on a closed circuit. This condition, however, does not involve much waste of energy if the ohmic resistance of the circuit of S be low enough. Here, then, is a transfer of energy from one circuit to another while the currents are direct currents in each circuit. To insure this being the case in S, the time of contact of segment on F with brush J must be selected so as not to permit any reversal, *i. e.*, the break of said segment with K must be timed to be made on the cessation of the first impulse or discharge from S. To do this an ammeter, responding to direct currents only, placed in the battery circuit, or in the leads from S, will indicate a maximum direct current when the segment F is of proper extent, and less under other conditions.

With the principles of the above apparatus in mind, it is easy to understand the action of my new form of induction coil, which may be described, briefly, as follows. The iron core I, Fig. 2, of the induction coil, is wound with the ordinary coarse primary coil and terminals provided therefor. Then a coil of intermediate gauge, between the inner primary and the outer secondary, is wound. It is to be capable of being connected across a circuit of 110 volts as with coil P, Fig. 1. This coil is the true primary or energy supplying coil, but for convenience and saving of wire I prefer to connect it in as the under portion of the real secondary circuit. It thus becomes useful as a part of the secondary itself and having several thousand turns, adds a considerable fraction to the total potential of the secondary. The secondary is, as usual, of quite fine wire of many thousands of turns, well insulated throughout.

In Fig. 2, the coarse coil is marked S P, and the intermediate coil, P S, while that outside is marked S. The functions of the coils S P and P S are to act as secondaries and primaries alternately.

This is, in fact, an essential function of S P, but is only incidental to coil P S, having been connected into the secondary circuit S, whose terminals are at *t t*. The break-wheels E F are like those of Fig. 1, except that in F there is a much shorter main segment and a condenser segment following, as in E. There is no battery in the circuit of S P, but it is put on dead short-circuit at intervals, just at the time P S is broken. Coil P S receives current from line at *p n*, at 100 to 200 volts, or more. On the break of this circuit at brush G the ampere turns, so to speak, are shifted suddenly into circuit of S P, closed on itself by J F. The consequence is that even at slow breaks no spark occurs at the rupture of G E. As soon as the current has been fully established in S P on short-circuit, and after brush Q has got entirely away from all metallic

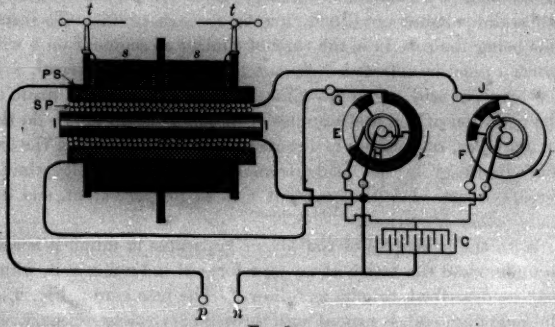


FIG. 2.

connections on E, the main segment of F breaks the circuit of S P which is conveying a very heavy current at low potential. The condenser C is put instantly across the break, and the spark flies between terminals *t t*. In this way a coil of the size of a six inch Ruhmkorff, gives a torrent of six inch sparks with an average current from a 110-volt line of about one-half an ampere. A simple motor or clock-work may be used to drive the break-wheels E F which are made of fair diameter to insure accuracy in operation. The best results are only to be obtained when the proportioning of the parts is carefully done, and with a knowledge of the result to be obtained.

The discharges are indistinguishable from those of a similar Ruhmkorff. In fact, the coil described might be used with the

same condenser C as an ordinary Ruhmkorff coil energized by batteries. In this case the terminals of the coil section P S are disconnected, brush J lifted and battery inserted between brush G and terminal of S P, which goes to J in Fig. 2. The break-wheel, E or F, when run with low potentials may be immersed in water in the usual way to facilitate sharp breaks, but the apparatus has been very successfully run, at full output, dry, or a little heavy oil on the break suffices. Also, the flux of current in S P may be made by a magnet to break its own circuit under water when the current has risen to a predetermined amount. In other words, it may be provided with the usual automatic break, damped or adjusted not to get into tremulous vibration. It will be seen from the above description that a new way of energizing an induction coil, or other transforming apparatus, has been embodied and that it consists in the rapid substitution of secondary and primary functions in the coil S P.

A paper to be presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th-28th, 1897.

[ADVANCE COPY—SUBJECT TO REVISION.]

THE EFFECT OF HEAT ON INSULATING MATERIALS.

BY PUTNAM A. BATES AND WALTER C. BARNES.

A paper on this subject was presented before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on May 20, 1896,[1] by Messrs. Sever, Monell and Perry. In the discussion which followed, the results were questioned by several members, and Mr. C. F. Scott cited some investigations of Mr. Skinner, who obtained curves which differed very considerably from those shown in the paper.[2]

This left the subject in such an unsatisfactory condition that it was decided to make further tests with the object of reconciling the differences or determining what the real facts are.

In our investigations, more attention has been paid to the actions which take place when one kind of material is subjected to tests while the conditions are varied, rather than a great number of tests on different materials, under the same conditions.

In fact, it has been deemed wise to conduct all the tests on one kind of material, it being safe to conclude from results previously obtained, that the action on it would be quite similar to that produced on other samples. Therefore, the ordinary "red fibre" insulating material having the general appearance of thick red paper, has been selected. Its thickness is about .009 inch.

THE APPARATUS.

This consists of two distinct parts, viz: the device for heating and that for testing the insulation resistance. The heating apparatus consists of a single electric heater, having a radiating surface of 47 square inches. This is nothing more than six resistance

1. TRANSACTIONS, vol. xiii, page 223.
2. *Ibid*, page 237.

coils tightly packed with asbestos in a short sheet iron cylinder, whose lower end is open. The terminals come from the ends of this set of resistance coils through the bottom of the heater, and are then connected through a suitable switch to a 110-volt circuit. This heater is supported on three porcelain insulators, which rest on a slab of slate one and one-half inches thick and one foot square. The heater takes exactly four amperes of current when all other resistance is cut out of the circuit.

Around the heater is placed an earthenware cylinder one foot high and nine inches in diameter. This provides an excellent method of keeping the heat in, and together with the electric heater secures perfect regulation of temperature. The terminals of this heating circuit are brought directly down and out from the heater through the base slab of slate to the terminals of a 110-volt lighting circuit and are thus kept entirely separate from any other part of the testing apparatus.

Resting on an asbestos collar and at a height of about 2 inches above the heater, in the earthenware cylinder, is placed a circular iron plate $\frac{1}{8}$ inch thick, which is one terminal of the testing circuit itself and is connected to one binding post of a Thomson high resistance galvanometer; a standard megohm being placed in series between the two.

The insulating material to be tested is wrapped on an iron cylinder 3 inches in length and having an external diameter of .875 inch, the insulation not quite reaching to the ends of the cylinder. The insulation is then wound with No. 26 B & S bare copper wire. This winding makes the other terminal of the testing circuit, and is connected to the other post of the galvanometer. The iron cylinder, upon which the insulation is placed, is then placed upright on the above mentioned iron plate. Thus it will be seen that the insulating material now separates the copper wire winding, as one terminal, from the iron cylinder which is now in contact with the iron plate, as the other terminal. The leading-in connections to these terminals pass through small holes bored in the earthenware cylinder. Glass insulators are used in these holes in order to prevent any current from creeping across from one wire to the other over the surface of the earthenware. Heavy covers of asbestos board are placed over the top of the earthenware cylinder and this again is entirely covered with a large glass globe.

The potential used in this circuit is 500 volts. A suitable

shunt, consisting of one or two turns of bare copper wire wound on each end of the sample of insulation, so situated that they would intercept and shunt past the galvanometer any current tending to leak along the surface of the insulation from the iron cylinder to the winding, that is, from one terminal to the other, is used in order that a deflection of the galvanometer needle will be produced only when a current actually passes through the insulating material under test.

In making the apparatus we have been very particular to eliminate all metals, with the exception of iron and copper, thus avoiding any possibility of the volatilization of zinc, which was one of the points raised in regard to the previous tests.[1]

This apparatus when complete works admirably, absolutely no difficulty being experienced with either the heating or the testing circuit.

The questions that we have attempted to answer by this investigation are four in number, viz.:—

1st. Does the presence of brass or other metals from which zinc may become volatilized, in the apparatus in which the test is conducted, affect the insulating material or its behavior?

2d. Why should one experimenter obtain an insulation resistance curve for fibre, whose minimum point is at about the same temperature as the maximum point of an insulation curve obtained from similar material by another experimenter?

3d. What effect on fibre insulating material is produced when it is subjected to conditions similar to those likely to occur in dynamo-electric machinery?

4th. What is the action, or actions, that take place when fibre insulating material is repeatedly heated from 20 degrees C. to 200 degrees C.?

Question No. 1 has been approached in the following manner: the resistance of the insulating material at the temperature of the air, or 20° C., being determined, the temperature is gradually raised until 200° is reached, when the test is discontinued. The time taken for this rise was exactly 2½ hours. Resistance measurements are made at frequent intervals, and from these curve No. 1 is plotted. The area of insulation tested being 5.5 square inches thickness = .0095 inch.

The position and shape of this curve agrees very closely with the results obtained by Messrs. Monell and Perry, who in their

1. TRANSACTIONS, Vol. XIII, page 233.

experiment used a brass cylinder, but a confirmatory test with a brass cylinder was also made in our apparatus. This experiment, was deferred until the completion of all other experiments.

Curve No. 2 thus obtained from a like sample of insulating material, thickness .0095 inch, area tested = 4.6 square inches, showed that the presence of brass in the apparatus does not affect the shape or position of the curve.

In taking up question No. 2, it is intended to prove, by comparative tests, that the position of the maxima and minima points of the resistance curves, depend upon the opportunity of escape given to the moisture originally contained in the specimen.

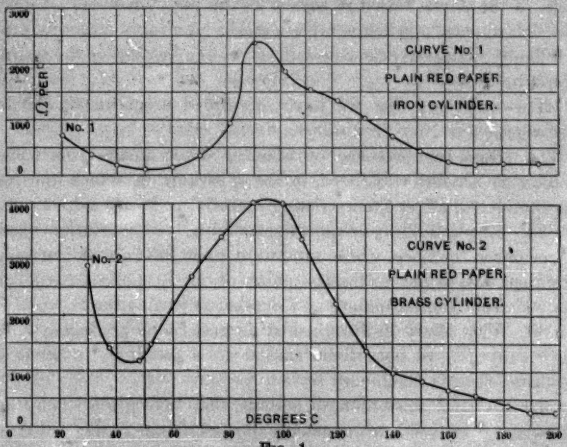


FIG. 1.

Curve No. 3 shows the results from a test on a sample of plain red fibre, thickness .009 inch, the area of insulation under test being 2.2 square inches. In this case five layers of No. 26 B. & S. bare copper wire were wound closely upon the fibre, the length of winding being only .8 inches.

Curve No. 4 has been obtained from a test on a specimen cut from same sample wrapped with a sheet of thin malleable iron held firmly in place by a number of layers of tightly wound copper wire, thus approaching the conditions under which the experiments cited by Mr. Scott were made. The area covered by this iron wrapping is 6.75 square inches. This test consisted

as before in gradually raising the temperature from that of the air to 200° C., the resistance being measured at frequent intervals. The curve obtained under the above conditions is almost identical with that published by Mr. Scott.[1]

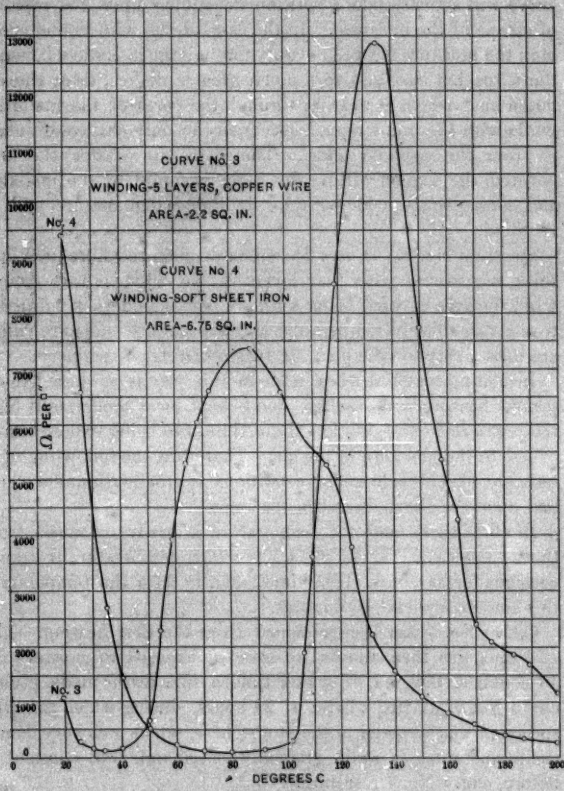


FIG. 2.

It is clear from these two experiments that the position of the curve may be shifted at pleasure by simply varying the oppor-

1. TRANSACTIONS, Vol. XIII, page 239.

tunity for the escape of the moisture originally contained in the insulating material. That is to say: if we wind our specimen with wire and only cover a small area, we find that the moisture has a much better chance of escape than if completely covered with an iron wrapping extending over a large area, and that the curve will actually take a position depending upon the rapidity of escape of the moisture. In the case of the wire-wound specimen the moisture escaped not only through the interstices between the wires, but also, and to a much greater degree, from the exposed ends which it reaches through the pores of the material; while with the iron-wrapped specimen the only chance of escape is from the exposed ends. Therefore, the greater the area covered, the longer will be the path traversed by the moisture and consequently a longer time or higher temperature will be required.

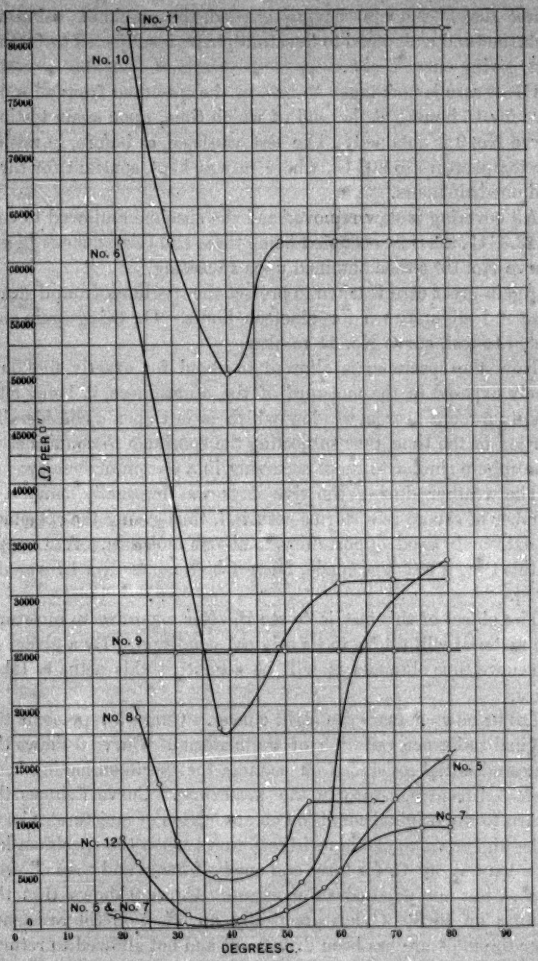
Question No. 3. A new specimen of plain red fibre .009 inch thick was wound with four layers of No. 26 B & S bare copper wire, the area covered being 4 square inches, and then subjected to the variations in temperature and exposure to moisture which are most likely to take place in dynamo electric machinery.

Insulating material when used in this way is subjected to repeated heating and cooling, being kept at a moderately high temperature for varying lengths of time, also being exposed more or less to the moisture in the air. Therefore, the following eight tests have been made under conditions approximating the above and upon the above described specimen.

In all of these tests the temperature is gradually raised from that of the air, 20° C., to 80° C., at which temperature it is kept constant for 3½ hours. The time taken to raise the temperature this amount is about 45 minutes.

Curve No. 5 has been obtained from the first heating. The specimen was then allowed to stand unexposed to moisture for 16 hours, at the end of which time a like test is made, giving curve No. 6. After a lapse of 24 hours, during which time the specimen was exposed to the atmosphere, which was very damp, the temperature is again gradually raised and kept constant as before, curve No. 7 resulting.

It will be seen by examination of these curves that the specimen after exposure to moisture returns to its original condition. The method of exposing the specimen to moisture is to remove the glass globe from the apparatus and the asbestos covers from the top


No. 11
No. 10
No. 6
No. 9
No. 8
No. 5
No. 7
No. 12
No. 5 & No. 7
Ω PER C.C.
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0
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60000
65000
70000
75000
80000

FIG. 3.

of the earthenware cylinder, the specimen itself being undisturbed. Three days, (72 hours) having elapsed, the specimen being undisturbed and unexposed to the atmosphere, is subjected to further test, giving curve No. 8.

Great care is now taken to protect the specimen from all moisture for 16 hours; at the end of which time, upon again testing, curve No. 9 is obtained. The test consisted, as before, in raising the temperature to 80° C., where it was kept constant for three and one-half hours.

All covering is now removed and the specimen allowed to cool to 23.3° C., the time occupied being three and three-quarter hours. Curve No. 10 is then obtained upon reheating.

Again great care is taken to protect the specimen from disturbance and all moisture for nineteen hours. On being again subjected to test, curve No. 11 results.

Now the specimen is allowed to stand for exactly five days freely exposed to the moisture of the atmosphere, it being situated in a room near a window which is left open a considerable portion of the time, thus subjecting the specimen to conditions of atmosphere similar to those occurring in a station or factory.

The weather during the five days was unusually damp. A number of severe rain storms occurred, thus giving the specimen an extremely good opportunity to absorb moisture. At the end of this time a test was made, from which curve No. 12 was derived.

The object of this test is to see if, after exposure to moisture, the material will return to its original condition. By a glance at the curve thus obtained it will be seen that this actually takes place.

Let us now compare the eight curves. Curve 5 represents the original resistance variation of the material. Curve 6 shows the increased initial resistance on cooling, the specimen having been protected from moisture in the meantime. Curve 7 shows the return to the original condition on absorption of moisture. Curve 8 the higher value of the resistance curve when the specimen has been kept at 80° C. for three and one-half hours and then allowed to cool, but not exposed to moisture. Curve 9 shows that the heating up to 80° C. has practically no effect on the resistance after the moisture has been driven out and not allowed to return. Curve 10 shows the condition into which the specimen was thrown when cooled while exposed to the atmosphere. Curve 11 indi-

cates that the moisture had again been practically all expelled and therefore, the heat produced no change in the resistance. Curve 12 shows that the specimen having been freely exposed to moisture has returned to almost its original condition. In all these

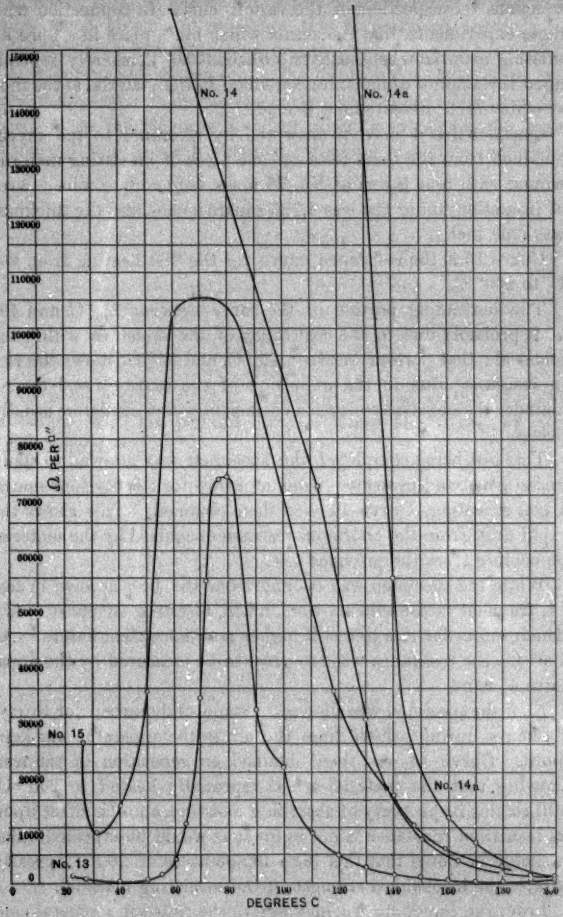

FIG. 4.

tests the resistance remained constant during the entire time that the temperature was kept constant. On examination, the specimen was found to be practically unchanged in appearance, mechanical strength or other qualities. One might, therefore conclude, on inspection of the various curves in connection with these experiments, that the action which takes place in a fibre insulating material when heated up to about 80° C., merely depends upon the amount of moisture contained in the material at the time at which each measurement is made.

Question No. 4 may be answered by reference to the curves obtained from the three tests on one piece of insulating material wound with four layers of No. 26 B. & S. bare copper wire. Area of insulation under test was 4.125 square inches, and the thickness was .009 inch.

Curve 13 is the resistance curve for the first heating from 20° C. to 200° C.

The descending portion of the curve between 23° C. and 40° C. is probably due to the coalescing of the moisture within the material; that portion between 40° C. and 80° C. shows the rise in resistance due to the expulsion of the moisture and the remainder the negative resistance coefficient which insulators usually possess.

This test being completed, the specimen was allowed to stand undisturbed and protected from moisture for twenty-four hours. Upon reheating, Curve 14 was then obtained. This shows the rapid drop from the enormous resistance acquired by the material on cooling from the previous test.

While the specimen was cooling from the heat applied in test 14, frequent measurements were made, resulting in curve (14*a*), which shows the rise to a still higher resistance than before. At 100° C., the resistance was too great to be measured by the apparatus at hand.

Now the specimen was allowed to stand undisturbed for thirty-six hours, during which time the air in the apparatus was kept moist. Curve 15 was then obtained on repetition of the test, showing that the material when repeatedly heated to 200° C. still retains its property of absorbing moisture, and the effect upon its insulation resistance is not as great as would be expected. But it should be noted that this high temperature of 200° C. greatly injures the mechanical strength of the insulating material.

From the foregoing we may derive the following general conclusions:

a. The presence of brass in the apparatus does not affect the shape and position of the curve.

b. The difference in the curves depends solely upon the amount of moisture contained in the material and its opportunity of escape.

c. Every time the specimen cools the resistance increases to a value much above any resistance that it possessed before, provided it is kept from absorbing moisture.

It is impossible to determine the limit of this action with the present apparatus. But all the curves, particularly Nos. 5 to 13, clearly show this stepping up effect, which is practically the same as the well known result obtained by baking insulating materials.

NOTICE.

Advance copies of other papers to be read at the General Meeting, will be printed in the June–July issue of the TRANSACTIONS.

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After printing the monthly, the papers and discussions are revised, repaged, and the sheets for the annual volume printed from the corrected type, and laid aside till the close of the year. As the index is made for the volume and **not** for the monthly parts, the complete volume sent at the end of the year becomes the permanent record. Upon its receipt the monthly parts are superfluous. They may be returned to this office at our expense, as there is a continual demand for separate copies of papers.

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